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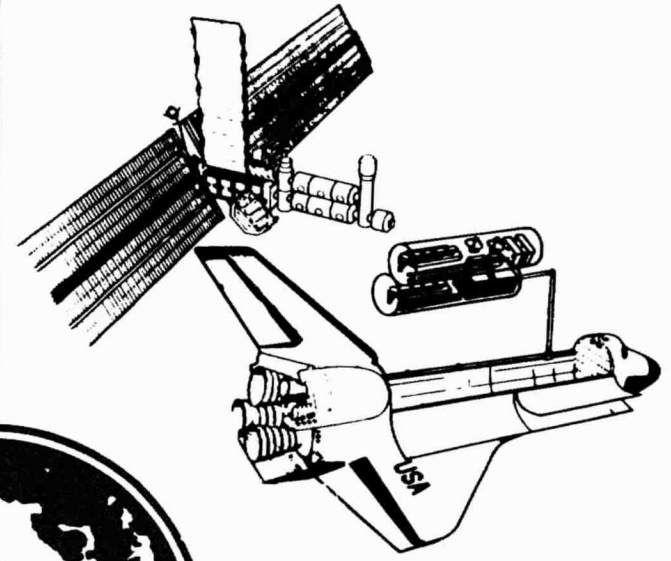
Definition of Satellite Servicing Technology Development Missions for Early Space Stations

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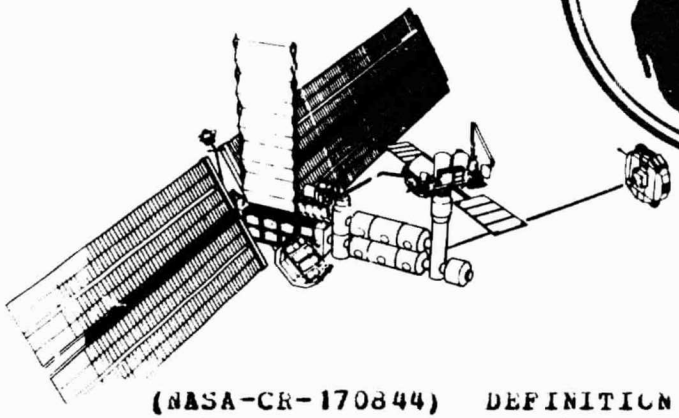
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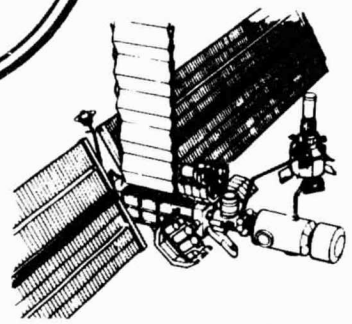
Final Report
Volume II — Technical
31 May 1983

Prepared for
NASA-Marshall Space Flight Center, Alabama
Under
Contract NAS8-35081 In Accordance With
Data Procurement Document No. 628, DR-4











(NASA-CR-170844) DEFINITION OF SATELLITE SERVICING TECHNOLOGY DEVELOPMENT MISSIONS FOR EARLY SPACE STATIONS. VOLUME 2: TECHNICAL Final Report (TRW Space Technology Labs.) 363 p HC A16/MF A01 CSCL 22B

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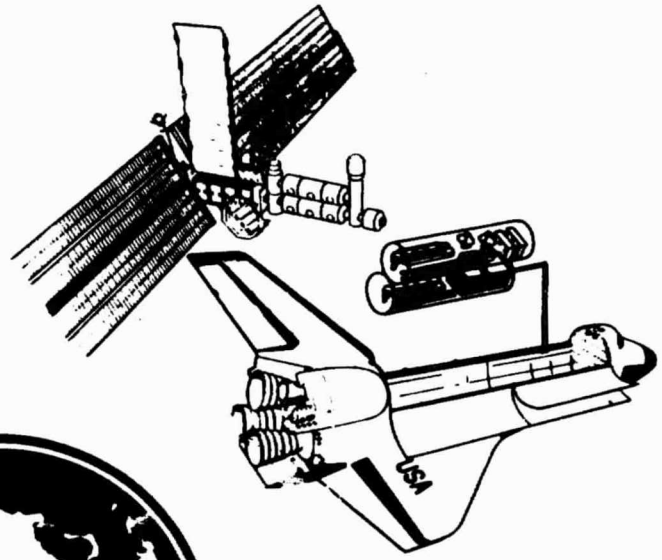
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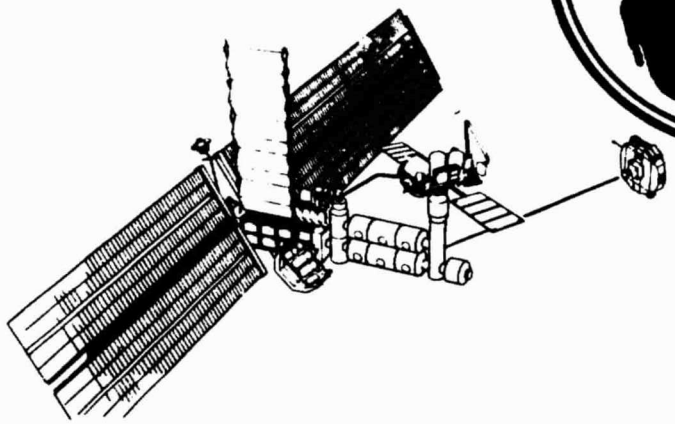
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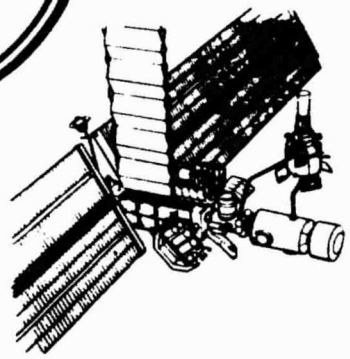
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PREFACE

This study, performed by the TRW Space and Technology Group under Contract NAS8-35081 for the NASA Marshall Space Flight Center, Alabama addressed the definition of candidate satellite servicing technology development missions that could benefit from the use of an early, 1991, manned space station.

The study started on 1 October 1982. Part I was completed on 31 May 1983. Three major tasks were addressed: mission requirements, mission definition of selected satellite servicing technology development missions, and programmatic analysis of the selected missions. It was found that almost all scientific, applications, and commercial missions planned in the 1985-2000 time period could benefit from some aspect of servicing on-orbit. The early space station was deemed vital as a necessary step in the establishment of on-orbit satellite servicing as an on-going, effective, national capability in the last decade of the century.

Part II, an extension to the work of Part I, will start about 1 June 1983 and continue for 18 months.

The study final report for Part I consists of three volumes generated in accordance with DR-s 4 and 5 of the contract data procurement Document No. 628:

Volume I	- Executive Summary
Volume II	- Technical Report
Volume III	- Environmental Analysis

This is Volume II - Technical Report

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Introduction

NASA is defining a program to establish permanent presence in space beginning in 1990. MSFC, during the past few years, has pursued study activities to meet this objective by defining an evolutionary space station program that can evolve from early, simple configurations into more complex and capable configurations as flight experience and technology advances. This approach permits the earliest manned operations and allows early flight experimental operations on advanced technologies.

Projections for candidate missions through the year 2000 have identified three key space operations which will require a manned presence in space: (1) assistance in deployment or assembly of large spacecraft systems, (2) periodic servicing of free-flying spacecraft accessible from a manned facility in low Earth orbit, and (3) operational support of spacecraft delivery missions needing high performance propulsion stages. An early space station would allow operational demonstrations to be exercised for extended periods of time and free from Shuttle constraints. Results from studies of these three mission areas, along with study results from other mission areas, will be integrated by NASA to define requirements that will assist in developing evolutionary space station configurations.

STUDY PLAN

This study was performed by TRW during the eight-month period 1 October 1982 to 31 May 1983. The tasks were: Determination of Mission Requirements, Mission Definition, and Programmatic Analysis, and included a total of nine subtasks.

In undertaking this study of defining Satellite Servicing Technology Development Missions (TDM) for Early Space Stations we used data from the existing literature on satellite servicing and our own extensive background and experience accumulated over more than 10 years of engineering analysis and design studies in this field. The study team performed its tasks in close collaboration with TRW's concurrent study effort, being performed under NASA Headquarters contract, NASW-3681, in defining Space Station Needs, Attributes and Architectural Options. Satellite servicing concepts, flows and operating requirements defined as part of that study provided needed input data for our TDM definition study. Our servicing TDM concepts were substantiated by taking the needs and attributes of early space station evolution into account. Of particular value was the data obtained by the satellite user servicing requirements survey conducted during the space station study, as well as servicing needs defined in TRW's recent 25 kW Space Platform concept definition studies, (Phase B), and Materials Experiment Carrier concept definition studies (Phase A) performed for Marshall Space Flight Center under Contracts NAS8-33956 and NAS8-33688.

Study Scope and Objectives. The statement of work called for an eight-month study. All technical work was completed within six months from contract go-ahead October 1982 through March 1983, allowing the seventh month, April 1983, for NASA reviews and the eight month, May 1983, for final report completion.

The study objectives were:

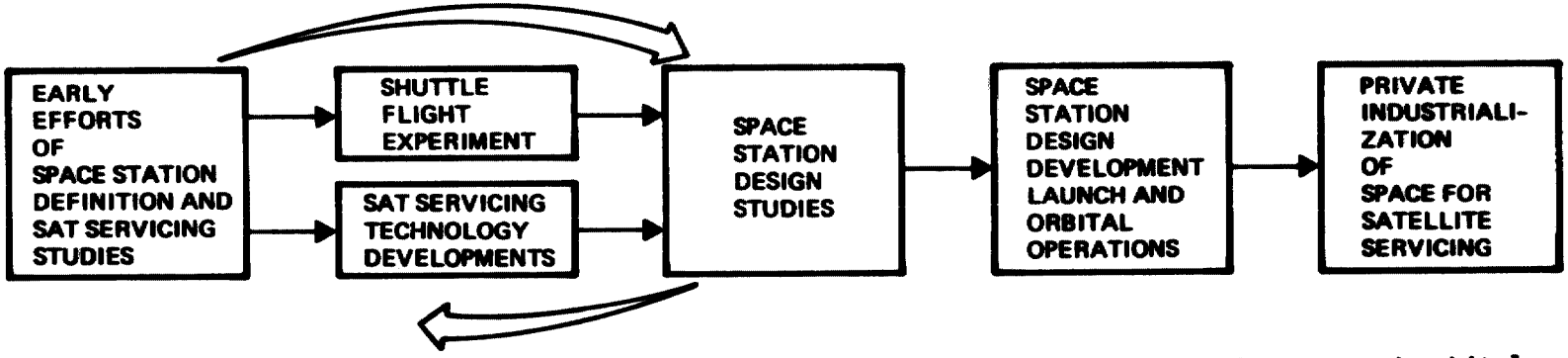
- Define the role of an early manned space station as a test bed in satellite servicing technology development
- Conceptually define satellite servicing Technology Development Missions (TDM) for an early manned space station

Study Results. Results produced by this study included the following products:

- Evolutionary Development and Flight Demonstration Technology Plan for Satellite Servicing
- TDM objectives and scenarios
- TDM requirements
- TDM mission definitions
- TDM design data (operations, time lines, mission parameters)
- Early space station support requirements matrix
- Cost estimates and trade-off-data
- TDM schedules
- Operational plans
- Environmental analysis report

Space Station Satellite Servicing Program

The NASA sponsored program to generate a national capability for assembly and servicing satellites on-orbit and for extending the usefullness of the manned space will evolve through steps or the next 15 years - mid 1985 through the year 2000. The steps are summarized in the sketch below:



Assuming the United States Space Station program proceeds to hardware development and orbital operations, we should witness in the last decade of this century the start of space-based spacecract servicing that is motivated by economic and operational considerations.

Study Follow-On

This report contains the results of Part 1 of the study. The present 3 task, 8 month effort by TRW will be followed, according to NASA/MSFC current planning, by a 6 task, 18 month addition to the work statement. The objectives of the follow-on contract work are:

1. Define the testbed role of an early (1990) space station in the context of a plan for the development of satellite servicing capability through technology demonstration activities, both ground and flight, which results in a fully operational satellite servicing capability by the late 1990's.
2. Define the detail satellite servicing technology development priority missions (a set of 5 TDMs) to be performed on an early manned space station including cost and schedules.
3. Assess impacts of satellite servicing operations on the space station, and to a lesser degree, space shuttle and TMS.
4. Assess satellite servicing potential on an early space station.

The first objective was also a stated objective of the first part of the study contract. The second objective adds the requirement of definition, costing and scheduling of selecting TDMs to the first part conceptualization of TDMs. The third and fourth objectives are new objectives to this second part of the study.

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TDM - A DEFINITION

TRW has used as a definition of a TDM, the definition provided by NASA. That definition narrows a TDM to a technology development which uses the space station. It derives a unique benefit by using the space station. A given TDM may, of course, be part of a total technology development with precursor tests using the STS and/or performed on the ground. The benefit of all technology elements developed as part of a TDM is to further the exploration of space. Each TDM, to be cost effective, must consider and quantify benefit versus cost. One way to avoid unrealistic cost is to plan TDMs which are not dead-ended i.e., have a residual value.

TDM – A DEFINITION

- A TECHNOLOGY DEVELOPMENT MISSION (TDM):
  - IS AN EXPERIMENTAL PROJECT AIMED AT SPACE TECHNOLOGY ADVANCEMENT
  - RECEIVES SUPPORT FROM THE SPACE STATION
- TDMs CAN:
  - HAVE VALUE FOR SCIENCE, APPLICATIONS, COMMERCIAL USES, NATIONAL SECURITY AND ENHANCEMENT OF NASA CAPABILITIES AND ROLE IN SPACE
  - DEVELOP TECHNOLOGY FOR LATER GENERATION SPACE STATIONS
  - INFLUENCE THE INITIAL SPACE STATION DESIGN
- TDMs WITH THEIR PROJECTED BENEFIT, IDEALLY, ARE INTERWOVEN WITH OTHER SPACE MISSIONS HAVING VALUE OF THEIR OWN

SUMMARY OF STUDY TASK FLOW AND SCHEDULE

The opposite page chart is the overall task flow of the TDM Satellite Servicing study. The study was highly coupled with the TRW Space Station Needs, Attributes and Architectural Options Study presently being conducted for NASA (TRW Contract NASW-3681). Therefore, much of the work and many results, of this Space Station Study were directly applied to the TDM Satellite Servicing study.

The three major tasks each took the outputs of prior tasks as principal input. On the flow, note the strong interaction between Task 2 (Mission Definition) and Task 3 (Programmatic Analysis) in the TDM definition trade studies.

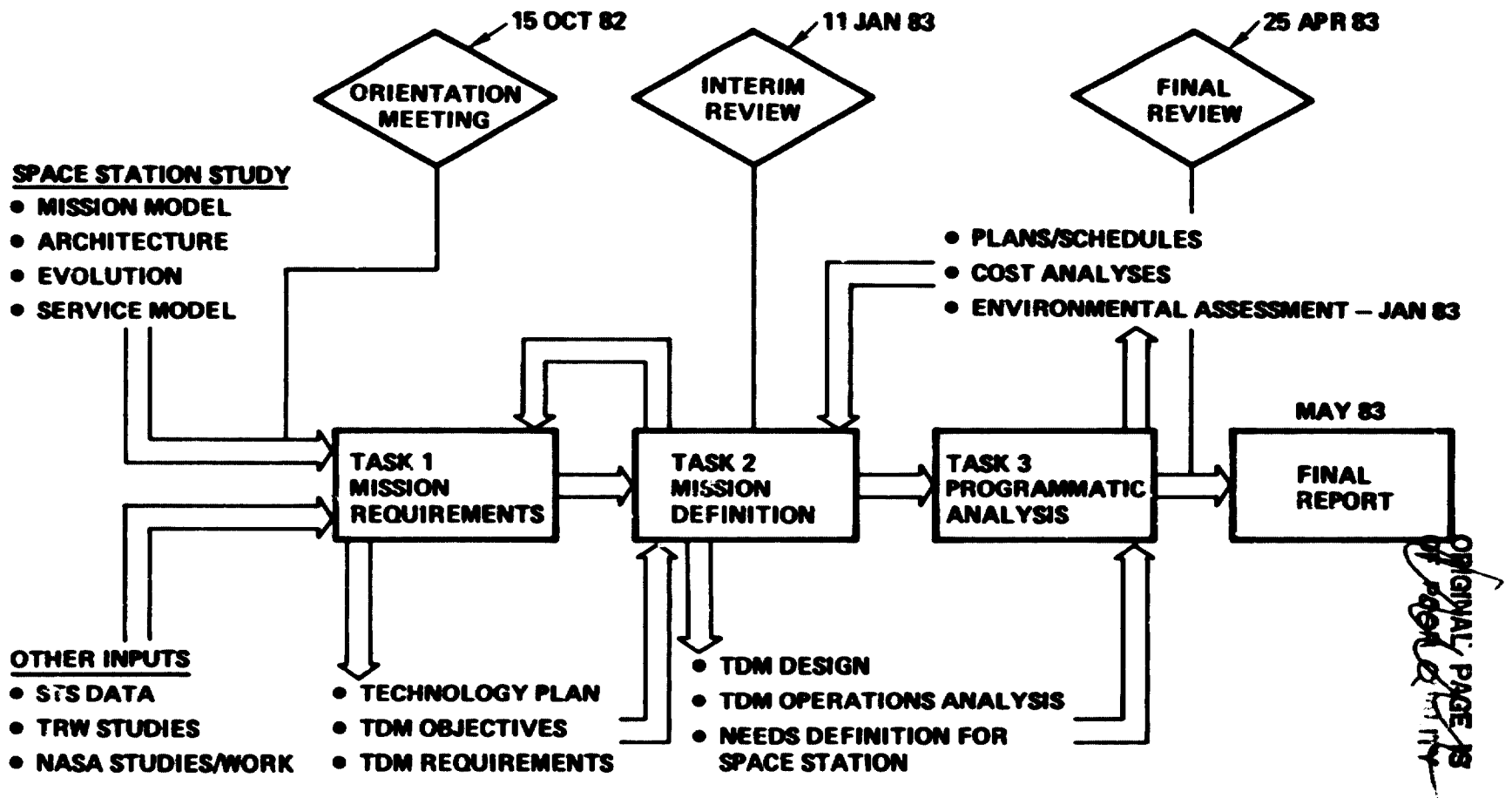
The two study objectives are shown on the bottom of the opposite page.

The three general "satellite servicing" mission/operations related subjects envisioned for study/definition effort were, in summary: (1) modification to space station itself to form both the initial and later configuration evolution, (2) repair and/or upgrading of satellites, and (3) assembly of spacecraft whose final configuration exceeds the individual STS payload capability. There have been many studies performed in these general topics in recent years and they provide a valuable source of information for this study. However, none of these studies in themselves fully considered the complete space station system, particularly its evolution over the mission time span. These studies were more concerned with an individual vehicle/mission aspect such as TMS, OTV, Power Module, Platform Structure, etc., in a configuration that did not change with time.

This study dealt with the feasibility and requirements for servicing and maintaining a free-flying satellite from a manned space facility. Although the servicing would be over the lifespan of the facility, special emphasis was placed on the early time period, that is starting about 1991.

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SUMMARY OF STUDY TASK FLOW AND SCHEDULE



TWO STUDY OBJECTIVES

• DEFINE TEST-BED ROLE OF THE EARLY SPACE STATION • DEFINE SAT SERVICING TDM's

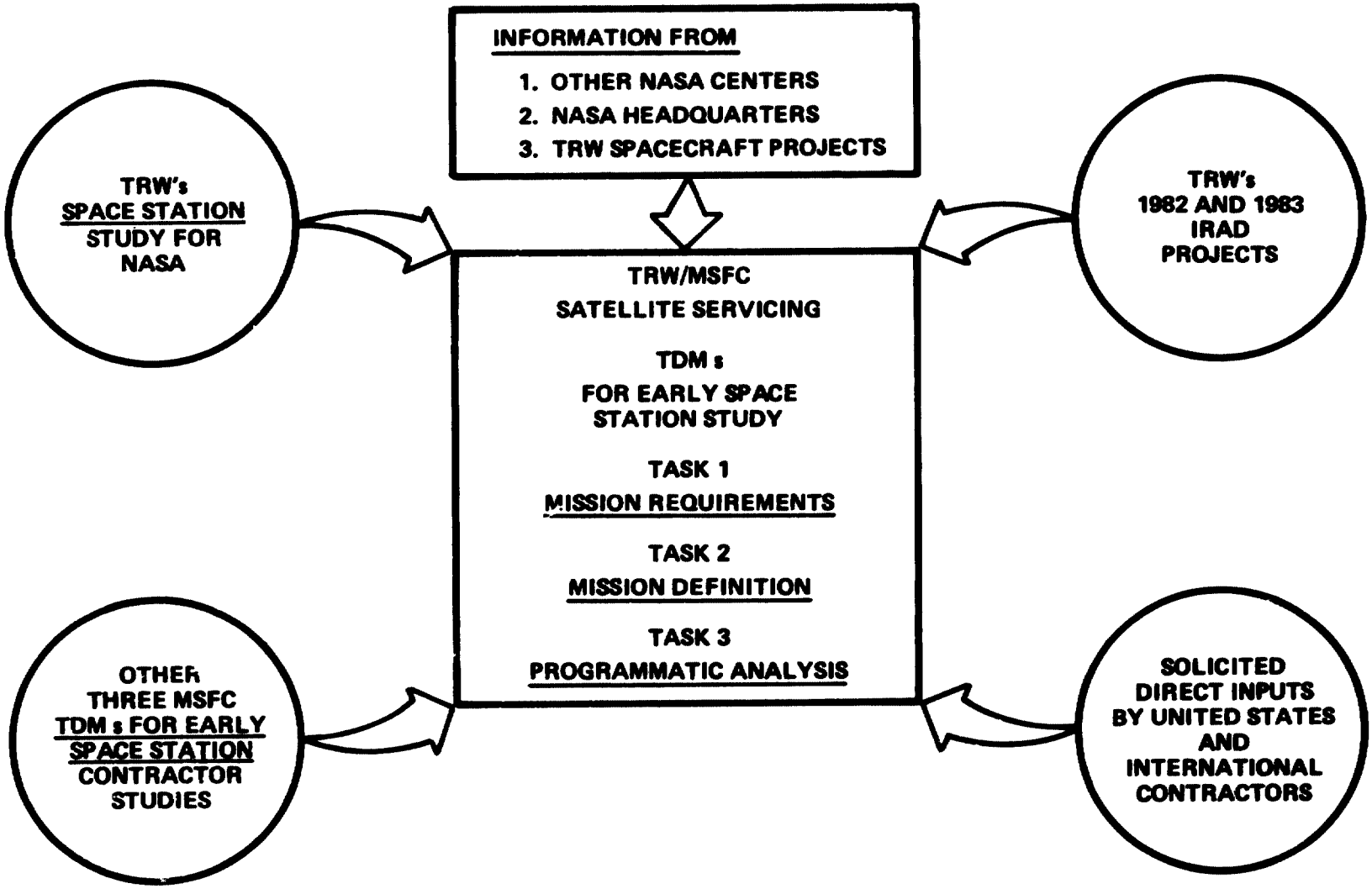
RELATED ACTIVITIES CONTRIBUTED TO STUDY RESULTS

An attempt was made to broaden the inputs to study results. Consequently, many organizations were contacted for satellite servicing technology ideas and suggestions. Source information was obtained from:

1. TRW Spacecraft Project Offices: GRO, TDRSS, DoD Spacecraft, Materials Processing in Space
2. NASA Centers/NASA Headquarters: Approximately 15 NASA people
3. TRW;s 1982 and 1983 IRAD: 12 Projects
4. TRW's Space Station Study (for NASA Headquarters): Approximately 8 TRW people from our Space Station Study team
5. Other three MSFC TDM For Space Station Contractors: Martin Marietta, Boeing, General Dynamics Convair
6. United States Companies: Hamilton Standard, Vought, Goodyear, Ball Aerospace, Fairchild, Ford Aerospace, General Electric, Hughes, RCA, Honeywell, and ESSEX
7. International Companies: Aeritalia, Aerospatiale, British Aerospace, ERNO, Matra, MBB, SAAB-Scania, and Spar Aerospace Canada

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RELATED ACTIVITIES CONTRIBUTED TO STUDY RESULTS



The basic top-level ground rules shown on the opposite page were used in the performance of this study.

Secondary ground rules for the conduct of specific study tasks and subtasks are given in subsequent parts of this report.

The guidelines for the cost estimate work of Task 3 are unique and are treated separately in the section of this document where Task 3 activity is described.

Each ground rule was adhered to in the conduct of the study. All were found to be useful as the work progressed. Sometimes two or more were applied to the outcome of a single TDM.

STUDY GROUND RULES

1. MAXIMUM USE OF AVAILABLE INFORMATION

2. SPACE STATION TO BE OPERATIONAL IN LOW EARTH ORBIT IN FY 1991

3. SPACE SHUTTLE IS THE EARTH LAUNCH VEHICLE

4. SATELLITE SERVICING OPERATIONS CAN OCCUR:
   - AT THE SPACE STATION
   - REMOTE FROM THE SPACE STATION

5. A TELEOPERATOR MANEUVERING SYSTEM WILL BE AVAILABLE TO SUPPORT ON-ORBIT OPERATIONS

6. MSFC's NEUTRAL BUOYANCY FACILITY AVAILABLE FOR PRECURSOR TESTS AND DEVELOPMENT

STUDY HIGHLIGHTS

This chart presents six summary statements representing the highlights of this eight month study.

1. Role of Space Station - A manned presence in space on a long term basis is vital to developing a national on-orbit satellite servicing capability. The shuttle, while a capable transportation system, is too constrained in its resources, crew numbers, and orbital stay time duration to be the long term solution to extensive orbital operations.

2. Spacecraft Manufacturers Survey - United States and International spacecraft manufacturers see high value in satellite servicing and endorse the use of the space station to support servicing functions.

3. TDMs With Operational Applications - Many TDMs have technology development content combined with operational mission objectives. Therefore, dead-ended hardware on-orbit is avoided.

4. Multiple Technologies Within A TDM - In order to maximize TDM effectiveness, we selected system level TDM's that incorporate more than one technology development element.

5. Pre Space Station Tests - Most TDMs can benefit from early tests in ground-based facilities and shuttle flights. These precursors to space station tests are needed to work out servicing techniques, mature support hardware, and train crews.

6. Initial TDMs - From 26 candidate TDMs, we selected five system level TDMs for design definition and programmatic analysis.

STUDY HIGHLIGHTS

1. SPACE STATION VITAL IN DEVELOPING A NATIONAL SATELLITE ON-ORBIT SERVICING CAPABILITY

2. SPACECRAFT MANUFACTURERS SEE BENEFIT OF SATELLITE SERVICING

3. TDMs IDENTIFIED THAT COMBINE TECHNOLOGY DEVELOPMENT WITH OPERATIONAL USEFULNESS

4. SELECTED TDMs ENHANCE A NUMBER OF TECHNOLOGIES

5. TDMs NEED GROUND AND SHUTTLE FLIGHT PRECURSOR/VALIDATION TESTS

6. STUDY DEFINED FIVE TDMs SELECTED FROM AN INITIAL LIST OF TWENTY-SIX

SPACE STATION ASSUMPTIONS

The principal assumptions regarding the system design attributes, operational aspects, and growth for the early space station are given on this chart.

These assumptions influenced the criteria for selection of the TDMs. After the TDMs were selected, these assumptions were then used in the detailed design definition of each TDM. A further breakdown of the design attributes on this chart was obtained from the TRW Space Station Needs, Attributes and Architectural Options study for NASA Headquarters (Contract NASW-3681).

SPACE STATION ASSUMPTIONS

TRW

SYSTEM DESIGN ATTRIBUTES:

1. A PERMANENT MANNED PRESENCE IN SPACE
2. BOTH MANNED AND UNMANNED ELEMENTS
3. LEO FOR THE FIRST MANNED ELEMENT, AT LOW INCLINATION
4. DELIVERY TO SPACE FROM THE SPACE SHUTTLE
5. EARLY SPACE STATION IOC FY 1991
6. INITIAL CREW SIZE 3-5 ROTATED BY THE SHUTTLE ABOUT EVERY 90 TO 120 DAYS

SYSTEM OPERATIONS ASPECTS

SPACE STATION ORBITAL AND GROUND OPERATIONS TAKEN FROM NASA SPACE STATION OPERATIONS WORKING GROUP'S BOOK 6, SYSTEMS OPERATIONS (FIRST EDITION), NOVEMBER 11, 1982

GROWTH

EVOLUTIONARY GROWTH FROM 1991 BY ON-ORBIT BUILD UP AND MODIFICATIONS TO LATER YEAR ADVANCED SPACE STATION CAPABILITY

STUDY SUMMARY

Dominant study results are given on the following two charts. They deal with:

- Satellite servicing technology developmet missions
- Role of the space station and the rationale for its importance
- Existing technology
- Current ground based facilities relevent to space-based satellite servicing
- Satellite servicing evolution

Development of space station satellite servicing capabilities will support construction of the space station; will extend the life of the satellites in orbit by replenishing propellants and pressurants, by replacing modules and by repair and refurbishment of critical parts; and will improve satellite reliability by performing operational verification of satellite systems (and repairing subsystems damaged during launch) prior to boost into higher operational orbits. Existing technology is insufficient, in various areas, to perform these servicing operations. In order to support development of servicing capabilities, certain important technologies and specific hardware elements must begin development now.

STUDY SUMMARY

1. SATELLITE SERVICING TECHNOLOGY DEVELOPMENT MISSIONS:

   - FIVE SYSTEM'S LEVEL TDMs WERE CONCEPTUALLY DEFINED, PLANNED, AND COSTED. THEIR SPACE STATION PRECURSOR TESTS, ROLE OF THE EARLY SPACE STATION, AND EVENTUAL BENEFITS WERE ANALYZED

   - TWENTY-FIVE TECHNOLOGY DEVELOPMENT ELEMENTS, ASSOCIATED WITH THE FIVE TDMs, WERE IDENTIFIED

2. SPACE STATION'S ROLE IN ON-ORBIT SATELLITE SERVICING HIGHLIGHTED AS:

   - PROVIDE LONG DURATION BASE FOR TDM IMPLEMENTATION

   - PROVIDE NECESSARY RESOURCES FOR CONDUCTING TDM OPERATIONS

   - PROVIDE LABORATORY MODE FOR EQUIPMENT TRIALS, TECHNIQUES DEVELOPMENT, ESTABLISHMENT OF STANDARDS, TRAINING, AND CONTINGENCY SERVICING

   - FIRST STEP IN THE EVOLUTIONARY GROWTH OF SERVICING FROM DEVELOPMENT TO OPERATIONAL STATUS

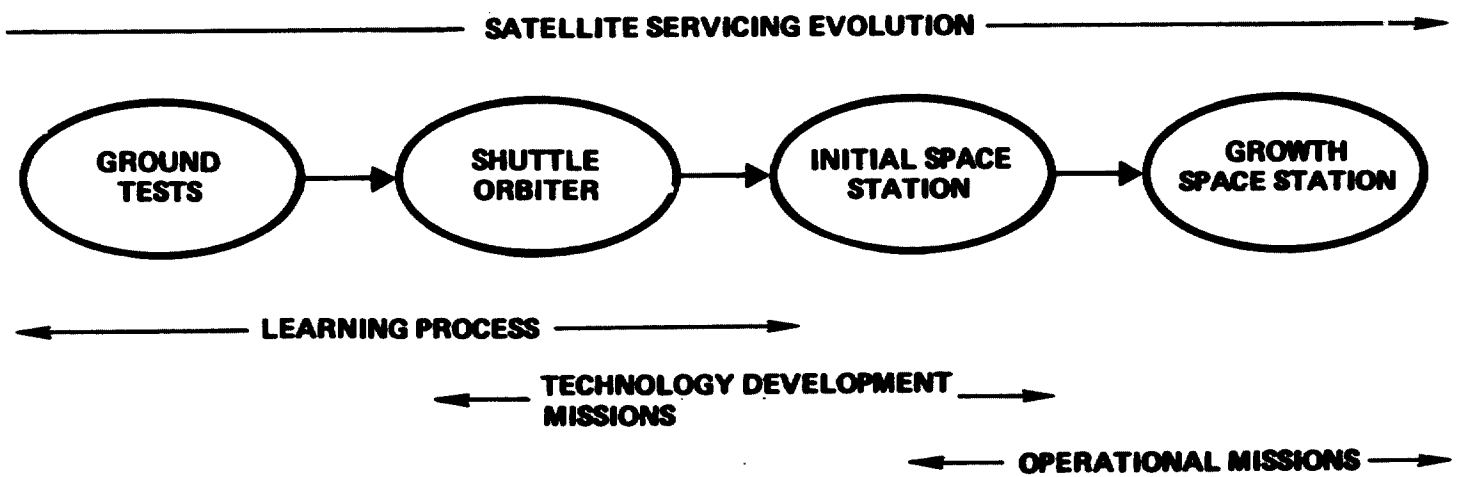
STUDY SUMMARY (CONT)

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3. EXISTING TECHNOLOGY IS INSUFFICIENT, IN SOME AREAS, TO ALLOW THE CONDUCT, AT PRESENT, OF OPERATIONAL ON-ORBIT SERVICING. STUDY IDENTIFIED A LIST OF IMPORTANT TECHNOLOGIES THAT MUST START NOW

4. SOME CURRENT GROUND-BASED ASSEMBLY/TEST, SIMULATIONS, AND TRAINING FACILITIES ARE RELEVANT TO SPACE-BASED SATELLITE SERVICING

5. SATELLITE SERVICING WILL PROCEED IN AN EVOLUTIONARY, RATHER THAN A REVOLUTIONARY MANNER. IT WILL BE CLOSELY TIED TO SPACE STATION EVOLUTION



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Task 1 Mission Requirements

TASK 1 MISSION REQUIREMENTS SUMMARY

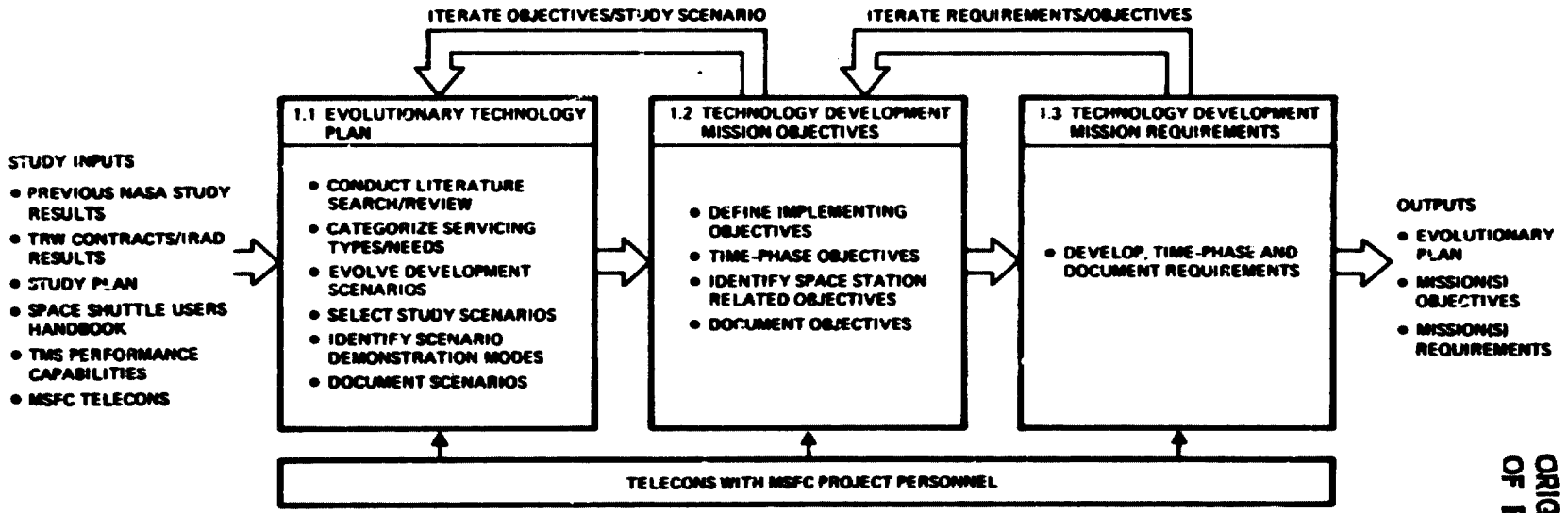
This section of the final report discusses the criteria, analysis and study which led, ultimately, to the selection of five TDMs for further definition in Task 2.2, Task 2.3 and Task 3. This section includes that work done in fulfillment of Task 2.1 TDM Conceptual Design which led to TDM selection.

Task 1 includes three subtasks which were addressed in the sequence shown in this chart. Also shown are principal study activities of each subtask as initially defined in the orientation briefing of October 15, 1982, along with study inputs and outputs.

First, after reviewing previous studies of satellite servicing concepts, a set of satellite servicing categories and needs was defined and technology requirements were derived. A plan for time-phased technology evolution associated with servicing objectives was formulated.

The next task involved the definition of candidate technology development missions and an outline of their mission scenarios. The total set included 25 TDMs representative of three principal servicing categories. From these a subset of five TDMs was selected to be studied in detail in Study Tasks 2 and 3. The criteria for their selection was formulated with emphasis on TDM characteristics that provide timely technology demonstration and actual operational support to representative NASA space missions in the early 1990's. Mission objectives and requirements were identified for each of the selected TDMs.

TASK 1. MISSION REQUIREMENTS - SUMMARY



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TASK 1 MISSION DEFINITION - SUMMARY

This chart, from the Study Plan, provides further detail of the flow of Task 1 and its contents, and describes the outputs to be provided from each of the subtasks.

TASK 1. MISSION REQUIREMENTS - SUMMARY

SUBTASK OBJECTIVES	INPUTS	APPROACH	EXPECTED OUTPUTS
1.1 EVOLUTIONARY TECHNOLOGY PLAN • SCENARIO(S) DEFINING TIME-PHASED NEEDS FOR SATELLITE SERVICING CAPABILITY • DEFINITION OF GROUND, SHUTTLE-SORTIE AND/OR EARLY SPACE STATION DEMONSTRATIONS OF NEEDED CAPABILITIES • DEFINITION OF TEST BED ROLE OF AN EARLY SPACE STATION IN SATELLITE SERVICING TECHNOLOGY DEVELOPMENT	PREVIOUS NASA AND TRW STUDY RESULTS, SPACE SHUTTLE USERS HANDBOOK, DATA ON TMS CAPABILITIES	1. REVIEW PRIOR STUDY DATA/RESULTS 2. SYNTHESIZE SERVICING NEEDS 3. POSTULATE DEVELOPMENT SCENARIOS 4. DEVELOP SELECTION CRITERIA 5. SELECT BEST SCENARIO(S) 6. IDENTIFY SCENARIO ELEMENTS	SCENARIOS FOR DEMONSTRATING SPACE STATION UTILITY IN SATELLITE SERVICING TECHNOLOGY DEVELOPMENT
1.2 TECHNOLOGY DEVELOPMENT MISSION (TDM) OBJECTIVES • DEFINITION OF TDM OBJECTIVES NECESSARY TO IMPLEMENT DEVELOPMENT SCENARIOS	DEVELOPMENT SCENARIOS SELECTED FROM SUBTASK 1.1, INCLUDING SUB-ELEMENTS IDENTIFIED	1. CATEGORIZE PLAN ELEMENTS 2. IDENTIFY MISSION TYPES 3. PREPARE MISSION-TYPE OBJECTIVES 4. TIME-PHASE OBJECTIVES	SET(S) OF MISSION OBJECTIVES FOR EACH SCENARIO THAT USES EARLY MANNED SPACE STATION FOR SATELLITE SERVICING AND THAT DEMONSTRATES THE UTILITY OF SUCH SERVICING
1.3 TECHNOLOGY DEVELOPMENT MISSION (TDM) REQUIREMENTS • REQUIREMENTS FOR TDMs THAT SATISFY MISSION OBJECTIVES	SET(S) OF MISSION OBJECTIVES, SPACECRAFT EPHEMERIS AND MASS DATA, TMS CAPABILITIES DATA, SPACE SHUTTLE USERS HANDBOOK EARLY SPACE STATION DATA	1. GENERATE CANDIDATE SPACECRAFT MATRIX 2. GENERATE REQUIREMENTS TREES 3. TEST REQUIREMENTS AGAINST CAPABILITIES 4. SELECT STUDY REQUIREMENTS SET(S) 5. PREPARE EVOLUTIONARY DEVELOPMENT AND FLIGHT DEMONSTRATION TECHNOLOGY PLAN	MISSION REQUIREMENTS TO DEMONSTRATE UTILITY AND TECHNOLOGY STATUS OF MANNED SPACE STATION FOR SATELLITE SERVICING, EVOLUTIONARY DEVELOPMENT AND FLIGHT DEMONSTRATION TECHNOLOGY PLAN

TDM MISSION CATEGORIES AND OBJECTIVES

The three TDM mission categories and their principal objectives are listed in this chart. These categories were defined at the outset of the study. In subsequent charts 26 candidate TDMs representative of the three categories will be listed and specific TDMs, selected for further analysis in Study Tasks 2 and 3, will be identified and characterized.

TDM MISSION CATEGORIES AND OBJECTIVES

CATEGORY I

SPACE STATION MODIFICATION AND BUILDUP

- SPACE STATION GROWTH
- MODIFICATIONS FOR EXTENDED OPERATIONS
- MAINTENANCE AND REPAIR

CATEGORY II

SPACECRAFT ASSEMBLY, TEST AND LAUNCH

- SPACECRAFT TOO LARGE FOR SINGLE SHUTTLE LAUNCH
- ASSEMBLY TOO TIME CONSUMING TO BE DONE BY SHUTTLE
- NEED FOR LARGER CREWS, MORE EXTENSIVE SUPPORT EQUIPMENT

CATEGORY III

SATELLITE SERVICING, REFURBISHMENT AND REPAIR

- ROUTINE SERVICING
- REPAIR/REFURBISHMENT AS NECESSARY
- SPACE STATION SERVES AS DEPOT AND OPERATIONS BASE

In the interest of cost effectiveness a combination between technology development/demonstration and operational mission support objectives was emphasized in defining the TDM candidates and also in selecting specific TDMs - one or two of each of the three TDM categories - for further detailed study. The ten technology development/demonstration objectives listed in the chart are linked directly to specific operational objectives, all of which are priority concerns in satellite servicing to be performed by an early space station.

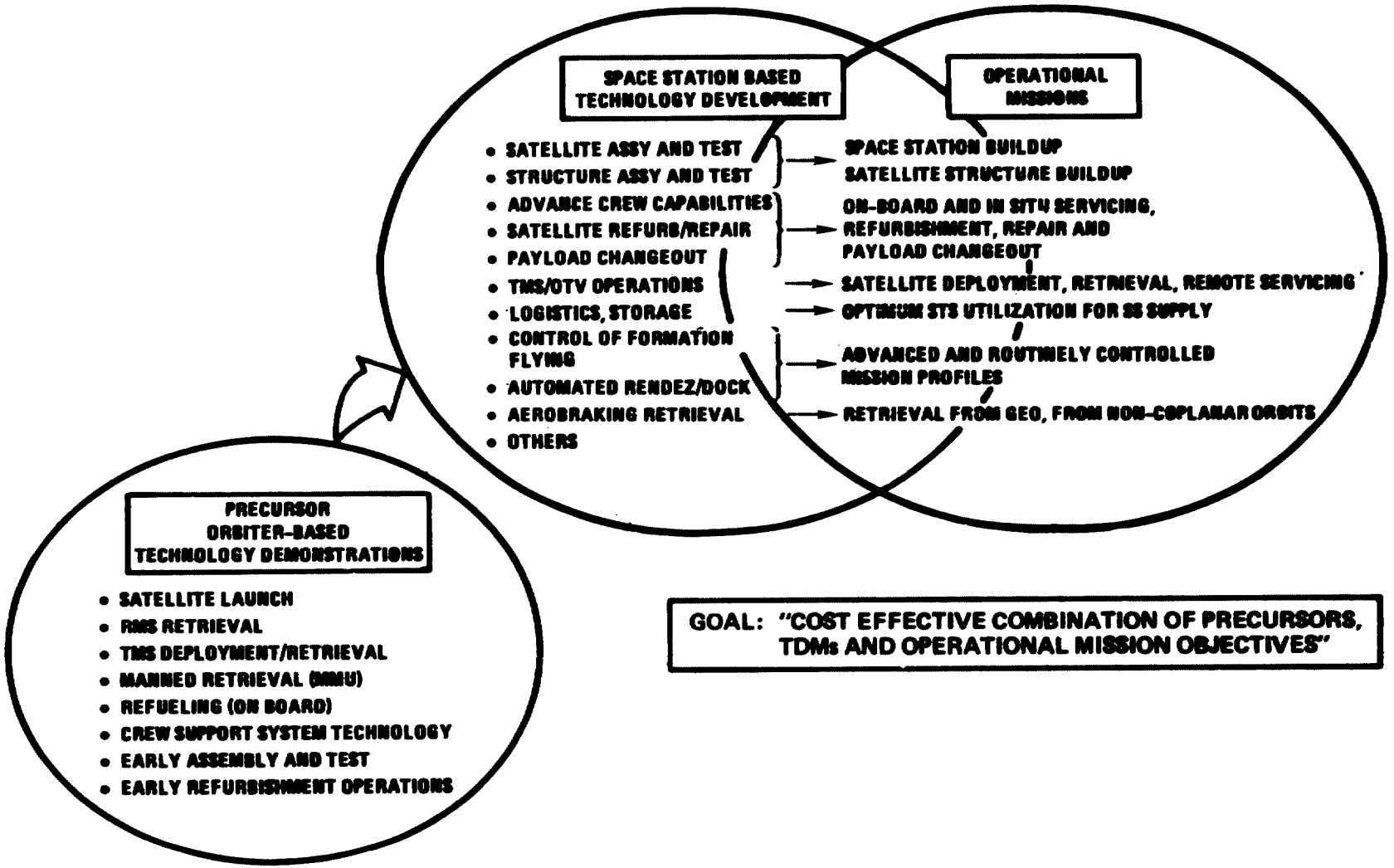
Transition from the servicing activities performed by the shuttle orbiter to those performed by a manned space station will be part of the required technology evolution. This transition involves:

a. Direct inheritance of servicing technologies and procedures developed by the shuttle orbiter.

b. Development of advanced technologies by the SS which exceed the orbiter's resources of single-sortie support capabilities, e.g., orbiter stay time.

However, servicing missions by the orbiter will continue to be important in the space station era because of the shuttle's inherently high mission profile flexibility. Thus, some aspects of SS servicing technology evolution will also feed back to enhance future orbiter servicing capabilities, e.g., utilization of OTV's, geo-stationary satellite retrieval, automated rendezvous and others.

TDM OBJECTIVES AND EVOLUTION



GOAL: "COST EFFECTIVE COMBINATION OF PRECURSORS, TDMs AND OPERATIONAL MISSION OBJECTIVES"

SPACE STATION STUDY MISSION MODEL SUPPORTS SERVICING NEED

The estimated average annual servicing requirements listed in this chart are based on data from TRW's current Space Station Study. The total of about 50 servicing events per year (averaged over the 1990 to 2000 time period) is broken down in terms of mission class (science, applications, commercial) and location or orbit type of the satellite/payload in need of servicing. Also indicated is the TDM category (or categories) that corresponds to these servicing requirements. Note however, that the large volume of traffic projected here (even during initial years of SS operation) will require routine servicing activities in addition to TDMs. The role of the TDMs, of course, is to usher in an era of routine servicing operations in the developing SS scenario.

Some key issues are called out on the right side of the chart. A realistic estimate of annual servicing requirements should include unplanned repair and refurbishment events which may increase the average annual servicing requirements to about 60. It is apparent that this projected large demand for servicing activities makes the development of cost-effective procedures in the decade of the late 1980's and early 1990's a pressing requirement involving both crew training programs and crew support equipment development.

SPACE STATION STUDY MISSION MODEL SUPPORTS SERVICING NEED

ESTIMATED AVERAGE YEARLY SERVICING REQUIREMENTS
(TRW MISSION MODEL, 1990 - 2000)*

	LOCATION/ORBIT TYPE[1]				TOTALS (PER YEAR)	
	ML	SP	LEO/MID	HE		
SCIENCE						
• ASTROPHYSICS		3	3	1	7	
• ENVIRONM OBSERV		2	1		3	
• EARTH/PLANETARY EXPLORATION				1	1	14
• LIFE SCIENCES	3				3	
APPLICATIONS						
• EARTH OBS/METEOROL	1		2		3	5
• MATERIALS PROC	1		1		2	
COMMERCIAL						
• COMMUNICATIONS				13	13	
• MATERIALS PROC[2]	1		16[2]		17	34
• REMOTE SENSING			4		4	
TOTALS[3]	6	5	27	15	53	
SERVICE CATEGORY	I, III	III	II, III	III		

(1) ML – MANNED LABORATORY ON SS
SP – SPACE PLATFORM (FREE FLYING)
LEO/MID – LOW AND MID-ALTITUDE ORBITS
HE – HIGH ENERGY ORBITS (GEO AND ESCAPE)

(2) MATERIALS PROCESSING PLATFORMS REQUIRE ROUTINE SERVICING AT HIGH ANNUAL RATE

(3) TOTALS INCLUDE BOTH ROUTINE AND MORE COMPLEX SERVICING REQUIREMENTS REFLECTING IN WIDE RANGE OF COST AND SUPPORT NEEDS PER EVENT

*INCLUDES LAUNCH OR SERVICING REQUIRED AT ALL ORBIT INCLINATIONS
SOURCE TRW STUDY OF SS ARCHITECTURE OPTIONS

SOME KEY ISSUES:

- ABOUT 50 PLANNED SERVICING EVENTS PER YEAR ESTIMATED
- ASSUME ABOUT 20 PERCENT ADDITIONAL UNPLANNED REPAIR/REFURBISHMENT REQUIREMENTS
- COST-EFFECTIVE SERVICING PROCEDURES ARE ESSENTIAL TO MEET THIS DEMAND ECONOMICALLY
- SHUTTLE-BASED SERVICING MISSIONS NEEDED, IN ADDITION TO SS-BASED SERVICING, FOR FLEXIBILITY OF SATELLITE ORBIT ACCESS

This matrix of satellite servicing operation classes versus satellite types that will require servicing illustrates the diversity of activities to be considered as well as the projected high incidence of servicing needs. It also differentiates between servicing functions to be performed on-board the space station and remotely ("in situ") at the orbital position of the satellite to be serviced. The latter tasks require the use of a teleoperator maneuvering system (TMS) operating autonomously or under continuous control by command link from the space station. Both types of servicing needs will be addressed in the TDM examples selected for detailed study.

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SATELLITE SERVICING OPERATIONS





SATELLITE SERVICING OPERATION \ SATELLITE TYPE	CO-ORBITING SATELLITES	SATELLITES IN DIFFERENT ORBIT	SATELLITES ASSEMBLED AT THE SPACE STATION	ATTACHED PAYLOADS	SELF-PROPELLED SATELLITES	SATELLITES REQUIRING TMS RETRIEVAL	SPACE STATION MODIFICATIONS
INSPECTION	X	X	X	X	X	X	X
RETRIEVAL					X	X	
MAINTENANCE/REPAIR	X	X	X	X	X	X	X
RESUPPLY/REPLACE	X	X	X	X	X	X	X
RECONFIGURE	X			X	X	X	X
ORBIT ASSEMBLY			X	X	X	X	X
MATE UPPER STAGE			X		X	X	
TEST/CHECKOUT	X	X	X	X	X	X	X
ON-ORBIT STORAGE					X	X	
DEPLOY	X	X	X		X	X	X

TECHNOLOGY EVOLUTION ISSUES

The chart summarizes the specific technology issues requiring further development in each of seven major areas of spacecraft, subsystem and mission engineering involved in satellite servicing. The items listed only represent "top level" concerns but indicate the diversity of technology issues that are being addressed. Asterisks on many of these entries indicate that the technology in question has a significant impact on mission and/or crew safety and should therefore be given appropriate attention in this context.

TECHNOLOGY EVOLUTION ISSUES

1. STRUCTURES AND MECHANISMS	• MODULAR STRUCTURES • SELF-LATCHING FIXTURES • INFLATABLES*	• BEAM ALIGNMENT DURING CONSTRUCT • SHAPE CONTROL OF LARGE ANTENNAS
2. AUTOMATIC AND REMOTE CONTROL	• PRECISION ALIGNMENT OF PAYLOAD INSTRUMENTS • REMOTE MANIPULATION (TMS) UNDER VIDEO CONTROL* • AUTOMATED RENDEZVOUS/DOCKING*	• TMS DEXTERITY AND AUTOMATION* • MANIPULATION SAFETY* • ROBOTS/ARTIFICIAL INTELLIGENCE*
3. DATA HANDLING/ MANAGEMENT	• VIDEO DATA COMPRESSION • DIAGNOSTIC ROUTINES	• DECISION MAKING LOGIC • AUTONOMOUS OPERATIONS*
4. PROPULSION AND MANEUVER MODES	• TMS/ADVANCED TMS • OTV EVOLUTION, MANNED OTV*	• REFUELING (HANDS-ON OR REMOTELY CONTROLLED)*
5. SPACECRAFT DESIGN FOR SERVICING	• ORU STANDARDIZATION • INTERFACE STANDARDIZATION	• CREW ACCESS* • TMS ACCESS • SATELLITE SAFING FOR ACCESS*
6. CREW SUPPORT EQUIP AND CREW PROCEDURES	• MANIPULATION AIDS* • VISUAL NAV AIDS (MMU)* • CREW TRAINING EVOLUTION/FACILITIES*	• MOBILITY AIDS* • INFLATABLE WORK STATION (SUPER SUIT)*
7. ORBIT MECHANICS	• ZERO-VELOCITY RENDEZVOUS MODE* • FORMATION FLYING AND PROXIMITY OPS	• AEROBRAKING* (GEO SAT RETRIEVAL) • AEROBRAKING* (NON-COPLANAR SATELLITE TRANSFER)

*PRINCIPAL AREAS INVOLVING MISSION/CREW SAFETY

The chart lists principal servicing activities to be addressed in defining and selecting TDMs for further study and presents an inventory of advanced technology requirements for these activities. Three levels of advanced technology requirements are indicated in this breakdown.

1)	major advances	-	dark circle
2)	moderate advances	-	open circle
3)	no significant advances	-	blank

From these entries a quantitative assessment of advanced technology requirements for each servicing activity is derived, as indicated by a score of total dark circle and open circle entries. High aggregate scores are marked by arrows at the right side of the chart. Similarly a score of how many servicing activities require each specific advanced technology and at what level is indicated at the bottom of the chart and again, high aggregate scores are marked by arrows.

This assessment presents a profile of overall technology requirements in servicing missions and identifies (a) dominant technology requirements and (b) the most technologically demanding servicing activities among those considered. The following chart will summarize these findings.

To obtain these results an informal survey was conducted among experienced TRW spacecraft and subsystem design specialists as to the major technology requirements within the TDM mission spectrum and servicing activities of interest in the framework of this study, (see Appendix A).

ADVANCED TECHNOLOGY REQUIREMENTS

TRW

TDM CATEGORY	SERVICING ACTIVITY / SYSTEM AND CHECKOUT TECHNOLOGY AREAS	STRUCT AND MECHAN	MECH ASE	ELECT INTEGR	ELECT ASE AND DIAGNOSTICS	PROPULSION	POWER AND THERMAL	ACS AND ROBOTICS	INSTRUM/TELEM	CREW SUPPORT EQUIP	CREW TRAINING AND PROCEDURES	ORB MECHANICS, GUID AND NAVIG	COMM'D AND DATA MGT	SCORE ●	SCORE ○	
I	MSS MODULAR BUILD-UP	●	●	●	●		●	○	○	●	●		○	7	3	←
II	SAT ASSY AND TEST	●	●	●	●			●	●	●	●		●	9	–	←
III	SAT RETRIEVAL, LEO	○				●		●	●	○	●	●	●	6	2	
III	SAT RETRIEVAL, GEO	○				●		●	●	○	●	●	●	6	2	
III	REFURB/REPAIR, ON MSS	●	●	●	●		●	○	○	●	●		●	8	2	←
III	REFURB/REPAIR, IN SITU	●				●	●	●	●		●	●	●	8	–	
III	IN SITU REFUELING	●			○	●		●	●		●	●	●	7	1	
I	FORMATION FLYING					○		●	●	○	●	●	●	5	2	
I	AUTOMATED RENDEZ/DOCK	●				●		●	●	○	●	●	●	7	1	
I	TETHER OPERATIONS	●	●	●	●			●	●	●	●	●	●	10	–	←
III	SCIENCE INSTR CHANGEOUT	●	●	●	●		●	○	●	●	●		○	8	2	←
III	MATERIALS PROC CHANGEOUT	●	●	●	●	○	○	●	●	○	●	○	●	8	4	←
II	LARGE STRUCT ASSY	●	●		○		○	●	●	●	●		○	6	3	
	SCORE ●	10	7	6	6	5	4	10	11	6	13	7	10			
	SCORE ○	2	–	–	2	2	2	3	2	5	–	1	3			

LEGEND:
● MAJOR ADVANCES
○ MODERATE ADVANCES
← MARK HIGHEST AGGREGATE SCORES

ADVANCED TECHNOLOGY REQUIREMENTS ASSESSMENT SUMMARY

The preceding assessment of advanced technology requirements of principal servicing functions in terms of major or moderate advances presented a profile of overall technology requirements in servicing missions and identified (a) dominant technology requirements and (b) the most technologically demanding servicing activities among those considered.

The facing chart lists five dominant technology requirements and six technologically most demanding service activities.

ADVANCED TECHNOLOGY REQUIREMENTS ASSESSMENT SUMMARY*

DOMINANT TECHNOLOGY REQUIREMENTS

- STRUCTURES AND MECHANISMS
- AUTOMATIC CONTROL, REMOTE CONTROL AND ROBOTICS
- INSTRUMENTATION AND TELEMETRY
- COMMAND AND DATA MANAGEMENT
- CREW TRAINING AND PROCEDURES

MOST DEMANDING SERVICE ACTIVITIES

- MSS MODULAR BUILDUP
- SATELLITE ASSEMBLY & TEST
- SATELLITE REFURBISHMENT & REPAIR (ON SS AND IN SITU)
- SCIENCE INSTRUMENT CHANGEOUT
- MATERIALS PROCESSING SAMPLE CHANGEOUT
- TETHERED OPERATIONS

*BASED ON A SURVEY AMONG TRW TECHNOLOGY EXPERTS

EMERGING KEY TECHNOLOGY REQUIREMENTS BY TDM MISSION CATEGORY

On the basis of the above technology requirements survey and assessment (see preceding charts) several key requirements emerge in each of the three TDM mission categories. The chart lists these requirements in terms of (a) technology drivers and (b) the respective technologies that are involved.

It is apparent that several of the key technology drivers are common to TDMs in each of these categories. These are:

- on orbit assembly
- manual, remote and automatic control
- checkout and verification techniques
- crew functions and capabilities
- advanced techniques in orbital mechanics, navigation and guidance

EMERGING KEY TECHNOLOGY REQUIREMENTS BY TDM MISSION CATEGORY

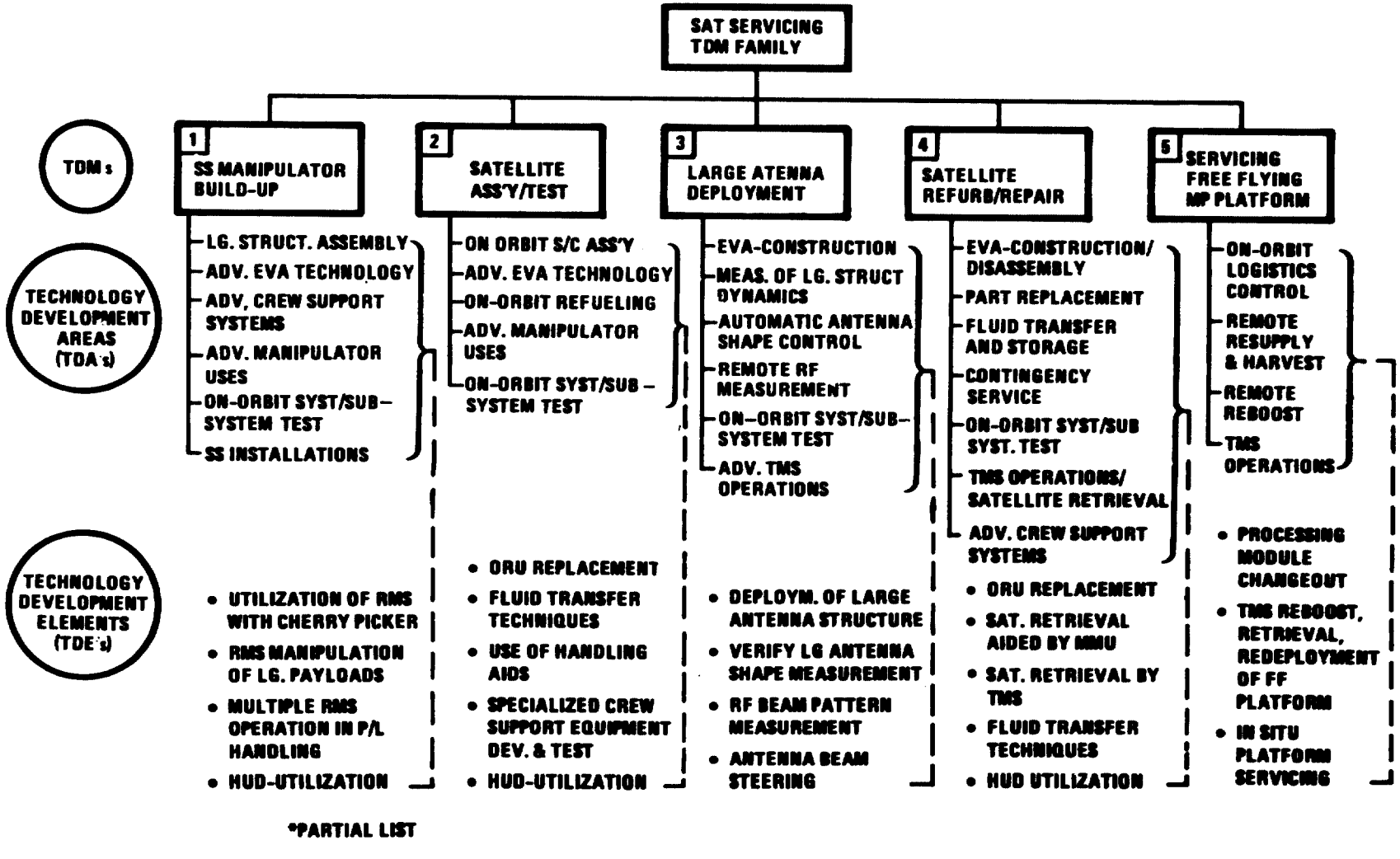
	KEY TECH DRIVERS	TECHNOLOGY INVOLVED
CATEGORY I	• ON-ORBIT ASSEMBLY	STRUCT, MECHANISMS, INTERFACES
	• CREW FUNCTIONS/CAPABILITIES	SAFETY, TRAINING
	• OPERATIONAL SUPPORT HARDWARE	MECHANISMS, CONTROL
	• ORBITAL MECHANICS	AUTOMATED RENDEZVOUS, FORMATION FLYING, NAV AND GUIDANCE, SENSORS
CATEGORY II	• ON-ORBIT ASSEMBLY	STRUCT, MECHANISMS, INTERFACES
	• CREW FUNCTIONS/CAPABILITIES	SAFETY, TRAINING
	• CHECKOUT/VERIFICATION	INSTRUMENTATION, DIAGNOSTICS
	• MANUAL AND REMOTE CONTROL	CONTROLS AND ROBOTICS
CATEGORY III	• OTV/TMS CAPABILITY	PROPULSION, CONTROL, MECHANISMS
	• CREW FUNCTIONS/CAPABILITIES	SAFETY, TRAINING, SUPPORT EQUIPMENT
	• CHECKOUT/VERIFICATION	INSTRUMENTATION, DIAGNOSTICS
	• MANUAL, REMOTE, AUTOMATIC CONTROL	CONTROLS AND ROBOTICS
	• OPERATIONAL SUPPORT	CDMS, COMM LINKS
	• ORBITAL MECHANICS	AUTOMATED RENDEZVOUS, NAV/GUID, SENSORS, AEROBRAKING

In analyzing the characteristics and implementation of various Technology Development Missions (TDM) a subdivision into a set of Technology Development Areas (TDA) and further, into Technology Development Elements (TDE), was found to be useful. This subdivision applies in particular to the precursor activities to be performed on the ground or on the shuttle orbiter, in preparation for the later TDM program that will have to await the advent of an operational space station. The above terminology will be used in subsequent charts and text as applicable.

It is apparent that a higher level (macroscopic) programmatic entity, TDM, as used in this report, encompasses a potentially large set of the lower level entities, TDA or TDE. Many of the same or quite similar elements are common to the different TDMs selected for study, as indicated by the family tree chart which illustrates the hierarchy and subdivisions of the TDMs being considered. Examples are advanced techniques of using the STS Manipulator, the Teleoperator, automated rendezvous and docking and crew support equipment for extra-vehicular tasks, including new heads-up display (HUD) technology applied to these tasks.

Because of this commonality it will be programmatically safe to proceed with various precursor activities in support of required TDEs even before a firm commitment is made to the specific TDMs formulated and recommended as the result of our study.

TECHNOLOGY DEVELOPEMENT ELEMENTS AND AREAS*



*PARTIAL LIST

CONCLUSIONS AS TO TECHNOLOGY REQUIREMENTS

The chart lists preliminary conclusions as to satellite servicing technology requirements as determined by the informal TRW in-house survey and our assessment methodology as presented in the preceding chart. One of the most significant results is the conclusion that no major technology breakthrough appears necessary in advancing the initial SS satellite servicing capability. The required technology advances rather are further evolution and engineering improvements of technologies already being established in shuttle orbiter based servicing that will predate the SS development and operational phases.

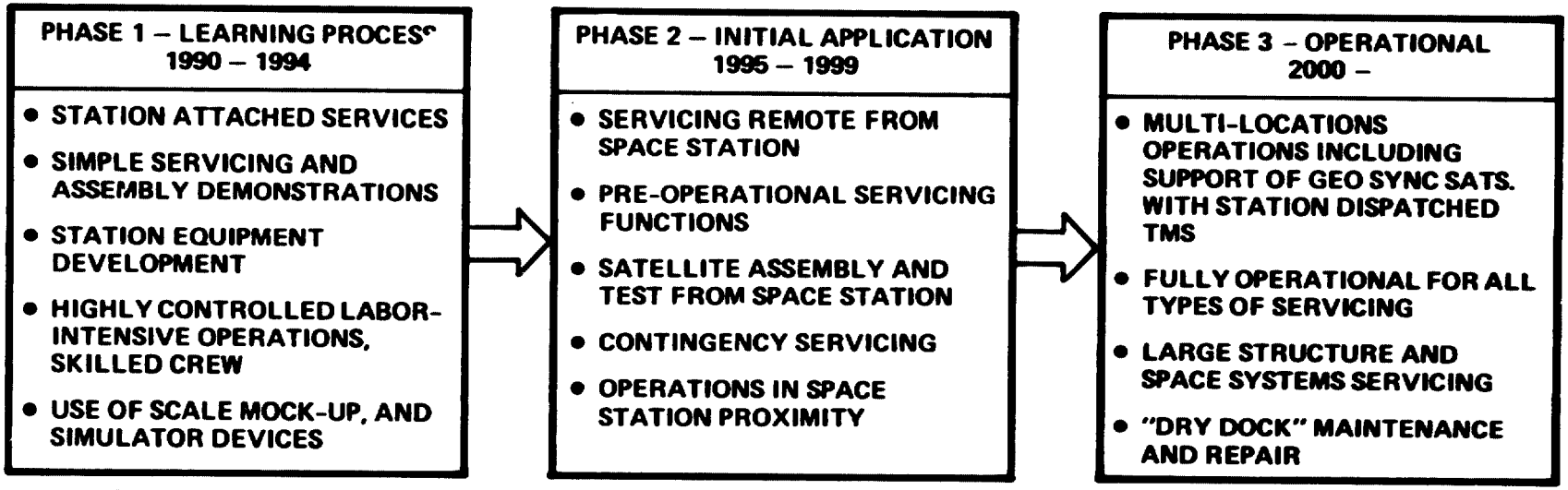
CONCLUSIONS AS TO TECHNOLOGY REQUIREMENTS

- KEY TECHNOLOGIES COMMON TO MULTIPLE TDM CATEGORIES ALTHOUGH SCENARIOS DIFFER
- SHUTTLE ORBITER COMPLEMENTS SERVICING TECHNOLOGY EVOLUTION, SERVES AS PRECURSOR/TESTBED
- NO BASIC TECHNOLOGY BREAKTHROUGH REQUIRED TO ACHIEVE INITIAL SATELLITE SERVICING CAPABILITY ON SPACE STATION (SS)
- GROWTH IN TECHNOLOGY ENHANCES/ENABLES SS SATELLITE SERVICING OPERATIONS
- CREW TRAINING AND SUPPORT EQUIPMENT/TECHNOLOGY ADVANCES CRITICALLY IMPORTANT TO EFFECTIVE TDM PERFORMANCE

SATELLITE SERVICING TECHNOLOGY AND SPACE STATION CAPABILITY WILL EVOLVE THROUGH LOGICAL PHASES

In this chart the anticipated evolution of satellite servicing technology and space station servicing support capabilities are traced through a learning phase, an initial applications phase, and a subsequent operation phase. The time periods of this evolution are indicated and principal servicing operations and support requirements in each phase are summarized. The following charts address the time-phased servicing technology evolution in terms of specific activities and milestones.

SATELLITE SERVICING TECHNOLOGY AND SPACE STATION CAPABILITY WILL EVOLVE THROUGH LOGICAL PHASES



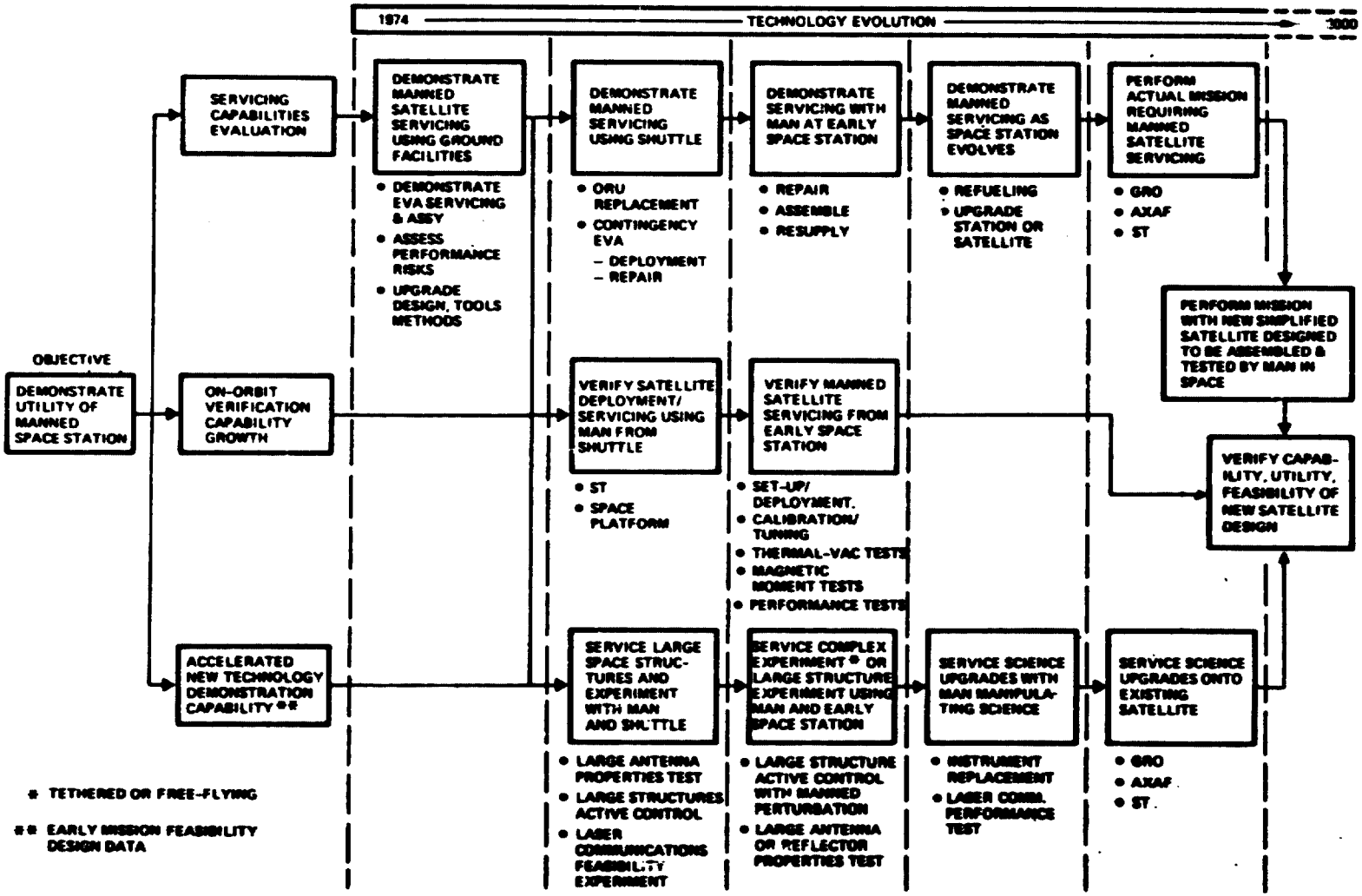
EVOLUTIONARY DEVELOPMENT AND FLIGHT DEMONSTRATION TECHNOLOGY PLAN

This flow chart of ongoing and projected major servicing technology events and activities was adopted from our orientation briefing of Nov. 15, 1982. It delineates event sequences along three principal lines of evolution:

1) Servicing capabilities evaluation
2) On-orbit verification/capability growth
3) New technology demonstrations

The flow originates with demonstration on ground facilities, going back to the mid-70's, and continues through shuttle-based servicing technology evolution in the 80's, leading to SS-based further developments in the 90's. The chart presents specific examples of key events in technology development, support equipment utilization and support activities to major satellite programs, leading to the milestone schedule shown in the following chart.

EVOLUTIONARY DEVELOPMENT AND FLIGHT DEMONSTRATION TECHNOLOGY PLAN



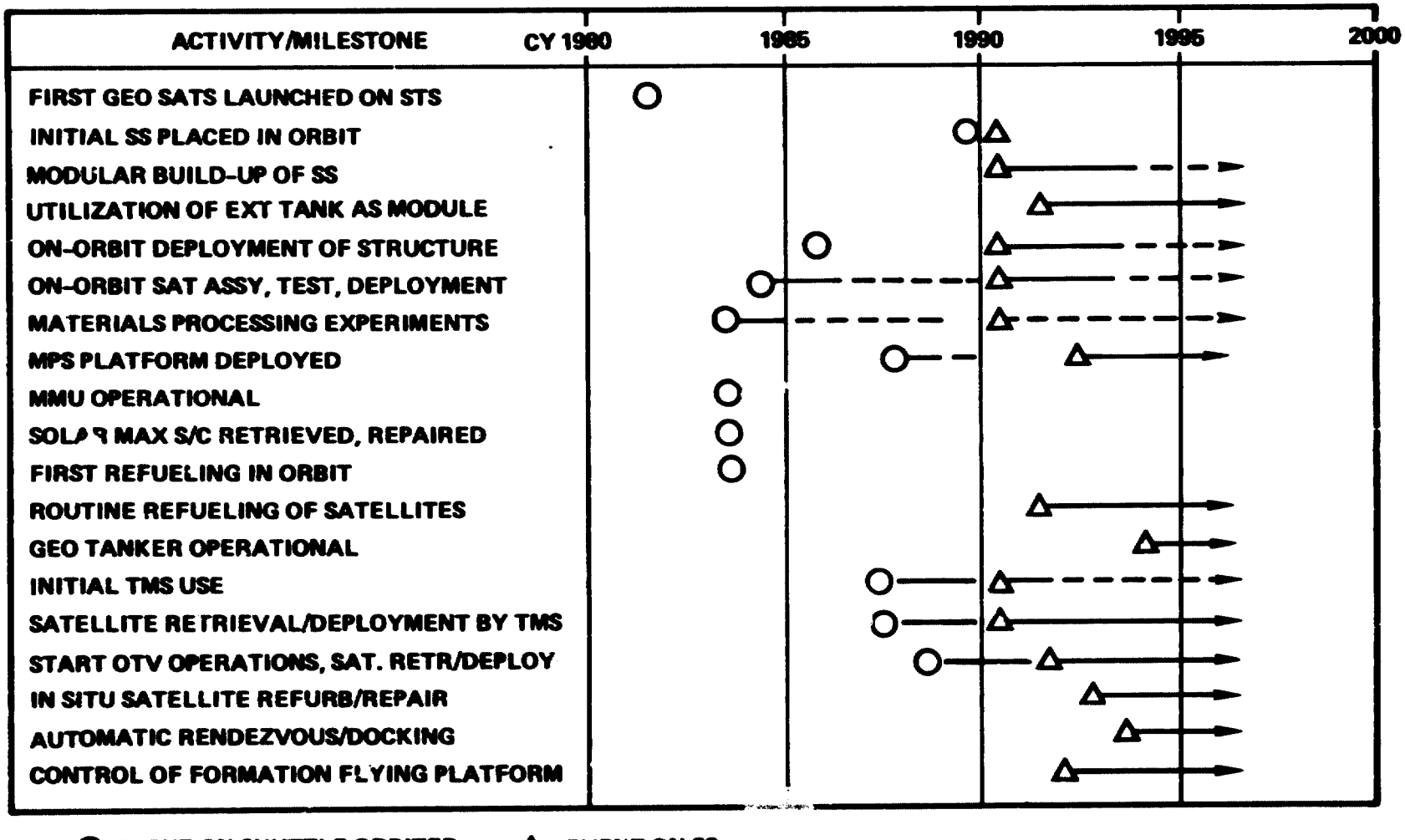
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SERVICING TECHNOLOGY EVOLUTION ON STS AND EARLY SS

The time-phased evolution of servicing technology is illustrated in this schedule of projected shuttle and space station (SS) activities and milestones. Servicing activities on the shuttle will begin with milestone events that are indicated by○ marks starting with the launch of two synchronous communication satellites in 1982 on STS 5. Those on the early SS are marked by △ symbols, starting in 1990-1991. In many instances the SS servicing activities evolve from those previously developed and demonstrated on the shuttle, as indicated in the chart. The continuation of servicing activities, once developed, is indicated by solid or broken lines to the right of the initial events marked by○ or △ . These projections are based on data from TRW's current SS evolution study and also from the earlier satellite servicing users' model (SSUM) by Gruman Aerospace. Beyond 1996 the transition from the "early" to the more fully developed SS is expected to take place.

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SERVICING TECHNOLOGY EVOLUTION ON STS AND EARLY SS



○ EVENT ON SHUTTLE ORBITER △ EVENT ON SS

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MAN'S ATTRIBUTES WILL ENHANCE
ON-ORBIT SATELLITE SERVICING

The essential role of the space station crew in performing satellite servicing functions is highlighted in this chart. Listed are the unique capabilities of the human operator and resulting key benefits accruing from human involvement, especially where judgement and decision making is required. Functional diversity, adaptibility, flexibility, improvisation, visual perception, and response to unforeseen contingencies and failure modes are attributes of the human operator that will be required in most servicing tasks. Substituion of automated/robotic systems would be complex and potentially more costly.

Analysis of space station crew size requirements which was performed during TRW's concurrent Space Station Needs, Attributes and Architectural Options study for NASA Headquarters* indicates a growth from 5 to 10 crew members will occur in the course of space station evolution in the 1990's. Thus the assignment of at least two or three men to tasks required for servicing TDMs can be accommodated comfortably. Summary charts included in Appendix C state the required crew time allocations.

*TRW document Z232.83-014, dated 8 February 1983, by H.L. Harkleroad

MAN'S ATTRIBUTES WILL ENHANCE ON-ORBIT SATELLITE SERVICING

MAN WILL:	RESULTING BENEFIT:
• SENSE UNPREDICTED PROBLEMS AND MAKE REAL-TIME DECISIONS ON THE SPOT	• AVOID UNANTICIPATED COSTLY FAILURES • JUDGE WHEN DATA GATHERING VIA SENSORS IS APPROPRIATE, HENCE REDUCE DATA TRANSMITTED TO EARTH
• PERFORM COMPLEX ASSEMBLY, INTEGRATION AND TEST OPERATIONS	• UNPACK, ASSEMBLE, CHECKOUT DELICATE INSTRUMENTS – LESS RUGGED INSTRUMENT DESIGNS POSSIBLE – COMPLEX MECHANISMS FOR CALIBRATION AND OPERATION UNNECESSARY • WITH HELP OF MANIPULATORS (E.G., RMS) ASSEMBLE OBJECTS TOO LARGE TO BE LAUNCHED INTACT • DEVELOP ON-ORBIT ASSEMBLY FACILITIES, HENCE REDUCE SATELLITE WEIGHT/COST
• SERVICE/MAINTAIN/REPAIR/REPLACE COMPONENTS OR MODULES	• EXTEND LIFE OF SPACECRAFT. IMPROVED PERFORMANCE THROUGH INSTALLATION OF NEWER TECHNOLOGY, REBIRTH OF FAILED SPACECRAFT AND/OR PAYLOADS
• BRING WORLD TECHNOLOGICAL KNOWLEDGE TO BEAR ON EACH SPACE PROBLEM VIA FLEXIBLE DIAGNOSTICS AND COMMUNCIATION WITH GROUND	• REPAIR OF FAILED SPACECRAFT WHERE THERE IS AN UNKNOWN CAUSE OF FAILURE
• UTILIZE VISUAL FEEDBACK TO CONTROL MOVEMENT OF OBJECTS	• SPACE DOCKING/BERTHING; LARGE STRUCTURE ASSEMBLY
• REDUCE ON-BOARD AUTOMATIC COMPLEXITY AND REDUNDANCY	• LOWER HARDWARE AND SOFTWARE COSTS

CREW ROLE AND PERFORMANCE ASSESSMENT

Each TDM if properly planned and executed will provide an opportunity to evaluate the crew's role in servicing operations and assess crew performance and productivity. It also should provide systematic in-flight data on man-machine interfaces to enhance crew safety and efficiency in future missions.

The program will be an expansion and refinement of similar programs, conducted previously on Apollo, Skylab and shuttle missions. This objective and the approach ot its implementation are outlined in this and the following chart.

It should be noted that the data taking and repeated task handling aspects of crew performance evaluation have the side effects of added work load, unavoidable delays and multiple interaction sequences between crew and equipment. Thus, crew evaluation procedures may not always be welcomed by project managers who are primarily concerned with minimum time expenditure and maximum crew productivity as directly related to specific assembly, testing, repair or refurbishment tasks. It will be necessary to coordinate the potentially conflicting interests of crew performance monitoring procedures and minimum-delay mission accomplishment well in advance of the flight date, and to negotiate schedules, operating sequences and resource allocations to the satisfaction of all parties concerned. To save the extra cost of systematic data taking would in many instances be false economy, especially since technology development will be a principal objective in these missions.

CREW ROLE AND PERFORMANCE ASSESSMENT

OBJECTIVE:

- EVALUATE THE FLIGHT CREW DURING TYPICAL SATELLITE SERVICING OPERATIONS TO HELP DETERMINE THE CREW'S OPTIMUM ROLE AND TO QUANTIFY CREW PRODUCTIVITY
- PROVIDE IN-FLIGHT DATA ON MAN/MACHINE INTERFACES TO ENHANCE THE EFFICIENCY AND SAFETY OF THE CREW IN FUTURE MISSIONS

APPROACH:

- CREW ROLE AND PERFORMANCE ASSESSMENT IS AN INTEGRAL PART OF EACH TDM
- THE ASSESSMENT WILL BUILD ON AND REFINE SIMILAR PROGRAMS PERFORMED ON APOLLO, SKYLAB, AND STS
- EACH TDM WILL CONSIDER FOR CREW ASSESSMENT
  - MULTIPLE APPROACHES TO A TASK
  - FAILURE SIMULATION
  - PLANNED MAINTENANCE SCHEDULE COMPRESSION
- DATA GATHERED WILL INCLUDE
  - REAL TIME MONITORING AND CRITIQUE (VIDEO/VOICE)
  - IN-FLIGHT DEBRIEFINGS
  - POST-FLIGHT DEBRIEFING AND DATA ANALYSIS

The evolvirg satellite servicing technology will be paced by growth in crew support equipment for tasks of increasing complexity. Listed in this chart are equipment items presently available in the inventory and those exepcted to become available in the near term.* This equipment will see first use on shuttle orbiter missions in the 1980's but will also be directly applicable or adaptable to use on the space station. Other crew support provisions and equipment needed in the long term as space station capabilities evolve may include such items as manned teleoperators or OTV's and inflatables that provide greater crew working comfort and manipulating ease in extra-vehicular tasks.

*Sources are in the shuttle-based servicing studies performed by Grumman and Lockheed (1980-81) and the Proceedings of the Satellite Servicing Workshop held at NASA/JSC in June 1982.

STS SERVICING HARDWARE FOR MANNED SPACE STATION

- PRESENT INVENTORY
  - REMOTE MANIPULATOR SYSTEM (RMS)
  - EVA PROVISIONS
  - MAN MANEUVERING UNIT (MMU)
  - STANDARD TOOL KIT
  - FLIGHT SUPPORT SYSTEMS (FSS) CRADLE
  - MINI WORK STATION (MWS)
  - TETHERS
  - MANIPULATOR FOOT RESTRAINT (MFR)

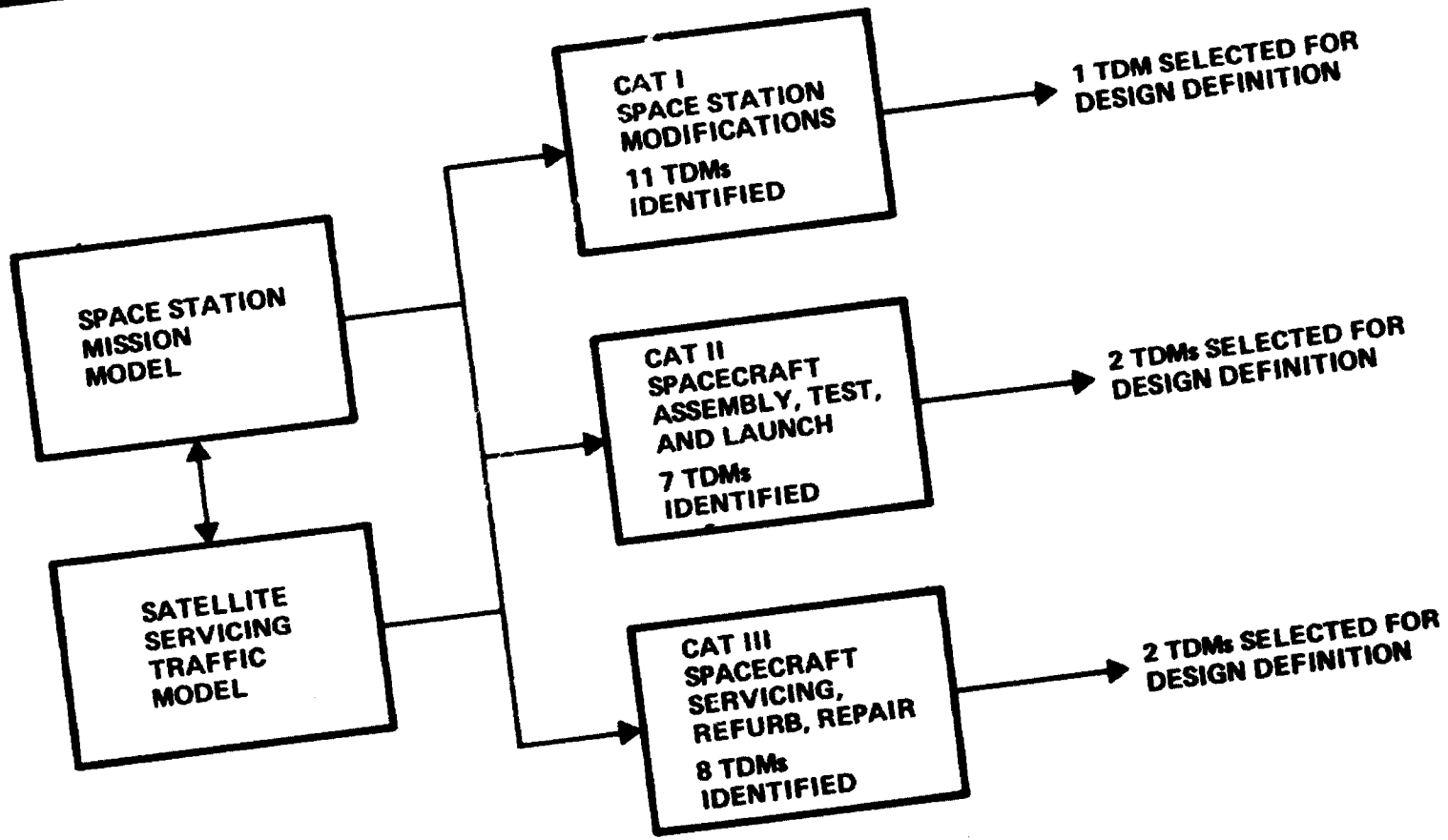
- EXPECTED INVENTORY ITEMS
  - TELEOPERATOR MANEUVERING SYSTEM (TMS)
  - OPEN CHERRY PICKER (OCP)
  - PAYLOAD RETENTION SYSTEM (PRS)
  - PAYLOAD INSTALLATION AND DEPLOYMENT (PIDA)
  - HANDLING AND POSITIONING AID (HPA)

TWENTY SIX TDMs IDENTIFIED; FIVE SELECTED FOR DESIGN

In the course of defining TDM mission objectives and requirements TRW has identified 26 TDM candidates in the three service activity/technology categories that have been previously discussed.

The chart summarizes the number of TDMs identified in each category and those selected for detailed design in Task 2. Subsequent charts will list all of these candidate TDMs and their technology demonstration and mission operation objectives.

TWENTY-SIX TDMs IDENTIFIED; FIVE SELECTED FOR DESIGN



TDM CANDIDATE MISSION LISTINGS

The next five charts present lists of TDM candidate missions, their technology development/ demonstration and operational mission support objectives, as previously discussed. From this spectrum of TDM mission candidates a set of five example TDM missions were subsequently selected for further definition.

CATEGORY I TDM CANDIDATES - SS BUILD-UP/MODIFICATION/UTILIZATION

TDM CANDIDATE MISSIONS	OBJECTIVES	
	TECHNOLOGY DEVELOPMENT AND DEMONSTRATION	OPERATIONAL CAPABILITY AND MISSION PERFORMANCE
1. INCREASE SOLAR ARRAY SIZE	DEVELOP STRUCTURAL/ELECTR MODIFICATION TECHNIQUES	INCREASE OPERATING CAPACITY
2. INSTALL REMOTE MANIPULATOR ARM, SUPPORT RAIL, AND USE IN CARGO HANDLING AND CONSTRUCTION	DEVELOP ASSEMBLY TECHNIQUE	ADDED HANDLING CAPABILITY
3. ADD BERTHING PORT(S) FOR ORBITER, SATELLITES	DEVELOP ASSEMBLY TECHNIQUE	ADDED ACCESS TO SS
4. ADD CREW HABITABILITY MODULE(S)	ADVANCE CONSTRUCTION AND INTEGRATION TECHNOLOGY	PROVIDE FOR LARGER CREWS
5. ADD INFLATABLE HANGARS AND WORK STATIONS	ADVANCE CONSTRUCTION AND INTEGRATION TECHNOLOGY	ADDED OPERATING CAPABILITY
6. PREPARE MSS FOR LARGE STRUCTURE ASSEMBLY	DEVELOP ADDED SUPPORT TECHNOLOGY	PERFORM MISSION REQUIRING LARGE STRUCTURE ASSEMBLY

CATEGORY I TDM CANDIDATES - SS BUILDUP/MODIFICATION/UTILIZATION (CONT)

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TDM CANDIDATE MISSIONS	OBJECTIVES	
	TECHNOLOGY DEVELOPMENT AND DEMONSTRATION	OPERATIONAL CAPABILITY AND MISSION PERFORMANCE
7. PROVIDE COMMAND/CONTROL CAPABILITY FOR PROXIMITY OPERATIONS (FREE FLYERS, TMS)	EXPAND SS OPERATIONS TECHNIQUES AND CREW	ADDED SS CAPABILITY
8. EXERCISE FORMATION FLYING MODES OF UNMANNED PLATFORM, OTHER SUBSATELLITES	DEVELOP PRACTICAL/EFFICIENT PROXIMITY OPERATIONS MODES	ENHANCE SS OPERATION CAPABILITY IN USING FREE FLYING PLATFORM(S)
9. PROVIDE AND DEMONSTRATE AUTOMATED RENDEZVOUS/DOCKING CAPABILITY	DEMONSTRATE AUTOMATED SATELLITE RETRIEVAL TECHNIQUES	USE DURING CARGO TRANSFER. TMS MISSIONS AND SATELLITE RETRIEVAL
10. ADD PROVISION FOR TETHERED PAYLOAD DEPLOYMENT AND CONTROL	DEMONSTRATE CONTROLLED TETHER DEPLOYMENT/RETRACTION	USE IN TETHERED PAYLOAD MISSION
11. DEVELOP AND DEMONSTRATE GEO SATELLITE RETRIEVAL IN AEROBRAKING MODE	DEVELOP PRACTICAL FUEL EFFICIENT AEROBRAKING TECHNIQUE	RETRIEVE GEO SATELLITE FOR REFURBISHMENT AND REPAIR

CATEGORY II TDM CANDIDATES - SPACECRAFT ASSEMBLY, TEST AND LAUNCH

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TDM CANDIDATE MISSIONS	OBJECTIVES	
	TECHNOLOGY DEVELOPMENT AND DEMONSTRATION	OPERATIONAL CAPABILITY AND MISSION PERFORMANCE
1. ASSEMBLE SPACECRAFT FROM PREFAB MODULES AND PERFORM COMPLETE TEST/CHECKOUT	STRUCTURAL ASSEMBLY TECHNOLOGY AND INTERFACE CONTROL	REQUIRED IN A&T OF SATELLITES EXCEEDING SINGLE SHUTTLE LAUNCH CAPACITY
2. ASSEMBLE AND TEST LARGE SPACECRAFT STRUCTURES	ASSEMBLY AND TEST TECHNIQUES	SAME AS NO. 1
3. PERFORM APPENDAGE DEPLOYMENT IN EVA AND/OR BY REMOTE MANIPULATION	DEMONSTRATE/EVALUATE DEPLOYMENT SKILLS	SIMPLER DEPLOYMENT MECHANISMS, STRUCTURES
4. PERFORM SATELLITE ASSEMBLY WITH AID OF MANIPULATOR	DEMONSTRATE REMOTE CONTROL CAPABILITY	INTEGRATION OF SPACECRAFT MODULES TOO LARGE FOR CREW HANDLING
5. DEPLOY LARGE ANTENNA STRUCTURE AND TEST RADIATION PATTERN	STRUCTURAL ASSEMBLY AND FORM CONTROL TECHNIQUES; MEASUREMENT BY FREE FLYER	REQUIRED IN NEXT GENERATION COMM SATELLITES AND RADIO ASTRONOMY MISSIONS
6. INTEGRATE LARGE SPACE STRUCTURE WITH FREE FLYING SATELLITE CORE MODULE AND DEPLOY/LAUNCH FROM MSS	DEVELOP ASSEMBLY, TEST AND LAUNCH TECHNIQUES OF LARGE STRUCTURES	SAME AS NO. 1, 2
7. PERFORM DISASSEMBLY OF SPACECRAFT FOR ON-STATION STORAGE OR RETURN TO GROUND	DEVELOP REMOTE AND MANUAL (EVA) MANIPULATION, TRANSFER AND STORAGE TECHNIQUES	SUPPORT RE-USE OF EXISTING SPACE HARDWARE

CATEGORY III TDM CANDIDATES - SATELLITE SERVICING/REFURB./REPAIR

TDM CANDIDATE MISSIONS	OBJECTIVES	
	TECHNOLOGY DEVELOPMENT AND DEMONSTRATION	OPERATIONAL CAPABILITY AND MISSION PERFORMANCE
1. MAINTAIN/UPGRADE ADVANCED SPACECRAFT	DEVELOP RETRIEVAL, HANDLING AND SERVICING TECHNIQUES	EXTEND ORBITAL LIFE OF SPACECRAFT SUCH AS GRO, LANDSAT
2. EXCHANGE OF SCIENCE INSTRUMENTS ON FACILITY-TYPE SPACECRAFT	DEMONSTRATE PRECISION ALIGNMENT AND INTEGRATION OF PAYLOAD ELEMENTS	NEEDED IN EFFECTIVE USE OF SPACE TELESCOPE, AXAF,GRO BY SCIENCE COMMUNITY
3. REPLACE FAILED/WORN ORUs	DEVELOP/DEMONSTRATE DIAGNOSTIC TECHNIQUES, HANDLING	ROUTINE REPAIR/REFURBISHMENT OF NEXT GENERATION SPACECRAFT
4. PERFORM FLUID TRANSFER (PROPELLANTS, COOLANTS, ETC) MANUALLY OR BY REMOTE CONTROL	DEVELOP/DEMONSTRATE SAFE FLUID TRANSFER METHODS	WILL BE NEEDED IN ROUTINE SPACE OPERATIONS IN LEO, GEO, ON S/C AND OTVs

CATEGORY III TDM CANDIDATES - SATELLITE SERVICING/REFURB./REPAIR (CONT)

TDM CANDIDATE MISSIONS	OBJECTIVES	
	TECHNOLOGY DEVELOPMENT AND DEMONSTRATION	OPERATIONAL CAPABILITY AND MISSION PERFORMANCE
5. REPAIR/SERVICE FREEFLYING SATELLITE "IN SITU" BY REMOTE CONTROL	DEVELOP DIAGNOSTIC TECHNIQUES AND REMOTE DELICATE HANDLING OPERATIONS	WILL BE NEEDED FOR SERVICE ON SATELLITES UNSUITABLE FOR DOCKING ON SS
6. REPAIR/SERVICE "IN SITU" WITH AID OF MANNED OTV, EVA OPERATIONS	DEVELOP/DEMONSTRATE CREW OPERATIONS REMOTE FROM SS	WILL BE USED FOR COMPLEX IN SITU SERVICING TASKS
7. RESUPPLY AND HARVEST PRODUCTS FROM FREE FLYING ZERO-G PROCESSING PLATFORM USING TMS	DEVELOP/DEMONSTRATE ACCESS TO AND REMOVAL/INSERTION OF SAMPLE MAGAZINES	NEEDED FOR ROUTINE OPERATION IN FF COMMERCIAL PROCESSING PLATFORMS
8. RETRIEVE AND PREPARE A S/C FOR RETURN TO GROUND VIA ORBITER	DEVELOP RETRIEVAL TECHNIQUES	WILL BE USED IN RETURNING SATELLITES FOR REFURBISHMENT ON GROUND

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TDM SELECTION CRITERIA

The chart lists 10 criteria and selection factors which we formulated as a guide to the selection of specific sample TDM missions for further study in Task 2. The first four are principal criteria to be met by the candidate missions to qualify for selection. The other six selection factors also express important considerations in the systematic selection process to be discussed below.

TDM SELECTION CRITERIA

PRINCIPAL CRITERIA

SELECTED TDM CANDIDATE:

1. PERFORMS USEFUL OPERATIONAL MISSION
2. SERVES TO DEVELOP/DEMONSTRATE SERVICING TECHNOLOGY (ENABLING/ENHANCING SERVICING CAPABILITIES)
3. COMBINES SEVERAL TECHNOLOGY DEVELOPMENT OBJECTIVES
4. IS REALISTIC AS TO PROJECTED COST, SCHEDULE AND SUPPORT EQUIPMENT REQUIREMENTS

OTHER SELECTION FACTORS:

5. CREW UTILIZED EFFECTIVELY
6. REQUIRED OPERATIONS EXCEEDING ORBITER STAY TIME
7. EVOLUTIONARY GROWTH POTENTIAL
8. INVOLVES SIGNIFICANT NEW TECHNOLOGY, DESIGN OR OPERATION
9. SATISFIES SEVERAL PROGRAM OBJECTIVES
10. SUPPORTS VARIETY OF OPERATIONS/EXPERIMENTS OR MISSIONS

SAMPLE TDM SELECTION RATIONALE

A quantitative grading of TDM mission types as to their suitability for further detailed analysis in the framework of this study was derived as shown in this chart.

The methodology employed rates each TDM mission type on a scale of 1 to 3 as to meeting the specific selection criteria that are listed at the top of the chart. Also a weighting factor w_i (1, 2 or 3) is assigned to each selection criterion to differentiate between their respective importance. The last column indicates the total score for each TDM mission type.

(a) by a weighted sum of ratings

$$S_j = \sum_i w_i \, r_{ij}$$

where r_{ij} is the rating of the j^{th} TDM mission type as to the i^{th} selection factor

(b) by grades ranging from 1 (minimum score S = 28) to 10 (maximum score S = 90)

On this basis five high-scoring TDM types with grades of 8, 9 and 10, marked by asterisks, were picked out as the missions warranting further detailed study.

Although this rating system is somewhat subjective and mathematically unsophisticated it permits a systematic selection of TDM examples for further study and exhibits the rationale of the selection process.

SAMPLE TDM SELECTION RATIONALE

TRW

TDM CATEGORY		TDM MISSION TYPE / SELECTION FACTOR / WEIGHTING FACTOR	Enables servicing capabilities (1) — 3	Enhances servicing capabilities (1) — 2	Essential to NSS evolution — 3	Combines several technol objectives — 2	Supports useful operational mission — 3	Supports variety of operations/experim — 3	Utilizes crew capab effectively — 2	Evolutionary growth potential — 2	Realistic cost — 3	Achieves future cost economy — 2	Realistic schedule — 2	Realistic support equipt reqmts — 1	Meets NASA/DoAF programmatic needs — 3	SCORE SUM	SCORE GRADE	
I	1	MODIFY/BUILD-UP SS	3	–	3	2	2	1	3	3	2	3	3	2	3	72	7	
I	2	INSTALL SS MANIPUL AND TRACK	3	–	3	2	3	3	3	3	2	3	3	2	3	81	9	*
I	3	ADD BERTHING PORT(S)	–	3	3	1	2	1	3	3	3	2	2	2	2	63	6	
II	4	SATELLITE A&T	3	–	2	2	3	2	3	3	3	3	3	3	3	79	8	*
II	5	LG STRUCTURE A&T	3	–	3	2	3	2	3	3	3	3	3	3	3	82	9	*
III	6	SAT SERVICE, ON SS	3	–	3	3	3	3	3	3	3	3	3	3	3	87	10	*
III	7	SAT SERVICE, IN SITU	3	–	3	3	3	3	1	3	2	3	3	2	2	76	8	
III	8	FLUID TRANSF & STORAGE	3	–	3	2	3	2	2	3	3	3	3	3	3	80	9	
III	9	SUPPORT FF PLATFORM, FORMATION FLYING	3	–	3	2	3	3	2	3	3	2	2	3	3	79	8	*
I	10	DEVELOP AUTOM R/DOCK	–	3	2	2	2	3	1	3	2	3	2	2	2	63	6	
III	11	SERVICE OTV	–	3	3	2	3	3	3	3	3	3	3	2	3	81	9	
III	12	RETRIEVE GEO SAT	3	–	3	2	3	2	2	3	1	3	1	1	3	68	7	
III	13	RETRIEVE SAT FROM NON COPLANAR	3	–	2	2	2	2	2	2	1	3	1	1	2	57	5	
I	14	TETHER OPERATIONS	–	2	1	1	2	2	3	2	1	2	2	1	1	46	4	

EVALUATION ALGORITHM: SCORE = $\Sigma W_{f_{ij}}$. W_i = WEIGHTING FACTOR, r_{ij} = RATING.
MAX SCORE = 90 (GRADE 10). MIN SCORE = 28 (GRADE 1)

* SELECTED TDM

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SELECTED EXAMPLE TDM's

This chart summarizes the types of TDMs selected for further study in each of the three TDM categories and the rationale for their selection, based on the findings derived from the preceeding chart. Note that each of these TDMs provides the desired combination of technology development/demonstration and operational mission objectives and meets most or all of the selection criteria previously identified. Thus it qualifies as a significant and cost-effective step in the evolution of SS servicing capability and, as such, will have a fair chance of programmatic approval once it is defined in greater detail (Task 2) and its cost and programmatic implications are more fully understood (Task 3).

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SELECTED EXAMPLE TDM'S

	SELECTED TDM	RATIONALE
CAT. I	1. SPACE STATION BUILD-UP BY MANIPULATOR INSTALLATION	• ESSENTIAL TO MSS ASSEMBLY AND CARGO HANDLING CAPABILITY
CAT. II	2. SATELLITE ASSEMBLY AND TEST	• BASIC STEP IN ALL FUTURE A&T MISSIONS ON MSS • FOLLOW-ON TO EARLIER ORBITER BASED MISSIONS
CAT. II	3. LARGE ANTENNA CONSTRUCTION AND TEST	• REPRESENTATIVE OF SPACE-BASED ACTIVITIES NOT FEASIBLE ON GROUND • NEEDED IN MANY FUTURE COMMUNICATIONS AND EARTH OBSERVATION MISSIONS
CAT. III	4. SERVICING OF SATELLITES (INCL REFURB/REPAIR, P/L CHANGEOUT)	• MAKE NEEDED USE GRO* POSSIBLE
CAT. III	5. SERVICING MATERIALS PROCESSING PLATFORM	• NEEDED TO SUPPORT ROUTINE COMMERCIAL SPACE PROCESSING

*GRO- GAMMA RAY OBSERVATORY TO BE LAUNCHED IN 1987

SELECTED TDMS ARE PART OF TECHNOLOGY EVOLUTION

The TDMs selected in each servicing category form a part of the require technology evolution by advancing the state of technology in various disciplines from that available prior to the advent of the manned space station. The selected TDMs thus have precursors in earlier ground-based and shuttle-based demonstrations. The chart lists specific examples.

SELECTED TDMs ARE PART OF TECHNOLOGY EVOLUTION

- SELECTED SATELLITE SERVICING TDMs HAVE PRECURSORS IN EARLIER GROUND AND STS DEMONSTRATIONS

TDM	EXAMPLES OF PRECURSORS
SPACE STATION MANIPULATOR BUILDUP	RMS: ANALYSIS SOFTWARE, SCENE GENERATION, 6-DOF FACILITIES, FULL SCALE GROUND & FLIGHT TESTS STRUCTURE ASSEMBLY DEMONSTRATION FLIGHT EXPERIMENT (SAFE) ON STS
SATELLITE ASSEMBLY AND TEST ON-ORBIT	MSFC UNDERWATER TESTING OF ON-ORBIT REPLACEMENT UNITS (ORU). MULTIMISSION MODULAR SPACECRAFT MODULE (MMS) SERVICING DEMONSTRATIONS. SOLAR MAX RECOVERY
SERVICING	SAME AS ABOVE PLUS FLUID TRANSFER DEMONSTRATIONS ON STS

TDM-RELATED ACTIVITIES PRECEDING SPACE STATION

The chart summarizes TDM-related activities to be undertaken in preparation of the mission itself which will involve the space station. These activities are classified into ground tests, with and without use of a neutral buoyancy facility, and activities conducted on or by the shuttle orbiter. In the latter category, Project COPE ("Capabilities for Opportunities, Payloads and Experiments") is referred to as an example, which will provide low-cost opportunities for exercising selected TDM-related functions on actual shuttle flights.

Note that crew involvement in checking out the feasibility, practicality, safety or effectiveness of certain TDM operations and hardware design approaches is a strong facet of most of the pre-SS tests and experiments listed in this chart.

TDM - RELATED ACTIVITIES PRECEDING SPACE STATION

SELECTED TDM	GROUND TESTS	NEUTRAL BUOYANCY FACILITY	SHUTTLE (EXAMPLE: PROJECT COPE)
1. SPACE STATION BUILD-UP BY MANIPULATOR INSTALLATION	• KINEMATIC TESTS WITH SCALE MODELS • INTERFERENCE ENVELOPES • SYSTEM EVALUATION TESTS	• MANEUVERING TESTS • CREW INTERACTION WITH RMS • ASSEMBLY METHODS	• OPERATOR CONTROL TESTS • LOAD CAPABILITY, CONSTRAINTS • ENVIRONMENTAL TESTS • TESTS ON UNIQUE MATERIALS
2. SATELLITE ASSEMBLY AND TEST	• ACCESS TO CRITICAL EQUIP • INTEGRATION PROCEDURES • SATELLITE FUELING TECHNIQUES • AUTOMATION TECHNIQUES	• INTEGRATION TIME LINES • CREW SKILLS, PRODUCTIVITY • DEVELOPMENT OF ASSEMBLY TOOLS, SUPPORT EQUIPMENT	• BUILD-UP OF CRITICAL PARTS • APPENDAGE DEPLOYMENT • ENVIRONMENTAL TESTS ON SELECTED SUBSYSTEMS, PARTS
3. LARGE ANTENNA CONSTRUCTION AND TEST	• ENVIRONMENTAL TESTS OF CRITICAL ANTENNA PARTS • INTERFERENCE TESTING • DEVELOPMENT OF UNIQUE STRUCTURES	• FIDELITY OF KEY ELECTRICAL/ MECHANICAL INTERFACES • DETERMINE ROLE OF THE CREW	• MAJOR EVENTS SEQUENCED IN MOST EFFECTIVE FLOW • DEPLOYMENT TESTS OF UNIQUE STRUCTURES, MATERIALS • ANTENNA SYSTEM TESTS
4. SERVICING A FACILITY TYPE SATELLITE	• DEVELOP CALIBRATION, ALIGNMENT PROCEDURES • DEVELOP INTERFACE HARDWARE	• CREW SKILLS, TIMELINES • ASSESS CREW PERFORMANCE AND HAZARDS • DEPLOYMENT TESTS	• WORK OUT CONTINGENCY PLANS • DEMONSTRATE AUTOMATED RENDEZVOUS AND DOCKING ON SIMULATED SPACECRAFT • DEMONSTRATE UNIQUE SERVICING SUPPORT EQUIPMENT
5. SERVICING A MATERIALS PROCESSING FREE-FLYING PLATFORM	• WORK OUT END-TO-END PROCEDURES ON MOCK-UPS • MODELING OF TMS/MPS OPERATIONAL SEQUENCE	• PRIORITIZE CHANGEOUT EQUIPMENT NEEDS • CREW SKILLS, TIMELINES • MAX SIZE EQUIPMENT CAN BE FOR SERVICING	• DEMONSTRATE USE OF RMS AND MMU IN MPS PAYLOAD AND SAMPLE CHANGEOUT • DETERMINE MPS EQUIPMENT LOCATION

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Precursor activities required in most TDMs identified in this study will include crew training and feasibility demonstrations by neutral buoyancy tests. TRW is currently participating in such tests in the MSFC NB facility to demonstrate installation / replacement of Space Platform solar array components.* The test specimen, a folded solar array wing mockup, its deployment arm and other items that form the mechanical interface with the Space Platform are illustrated in this chart. Similar tests also are planned for removal/replacement of Space Platform on orbit replaceable units (ORUs).

The detailed study of TDM implementation and operational sequences, in Task 2, will refer to these as part of the precursor activities required in servicing technology development.

*See TRW document - "Space Station Orbital Maintenance and Growth Operations - Neutral Buoyancy Simulations" by G. Johnson, 21 April 1983

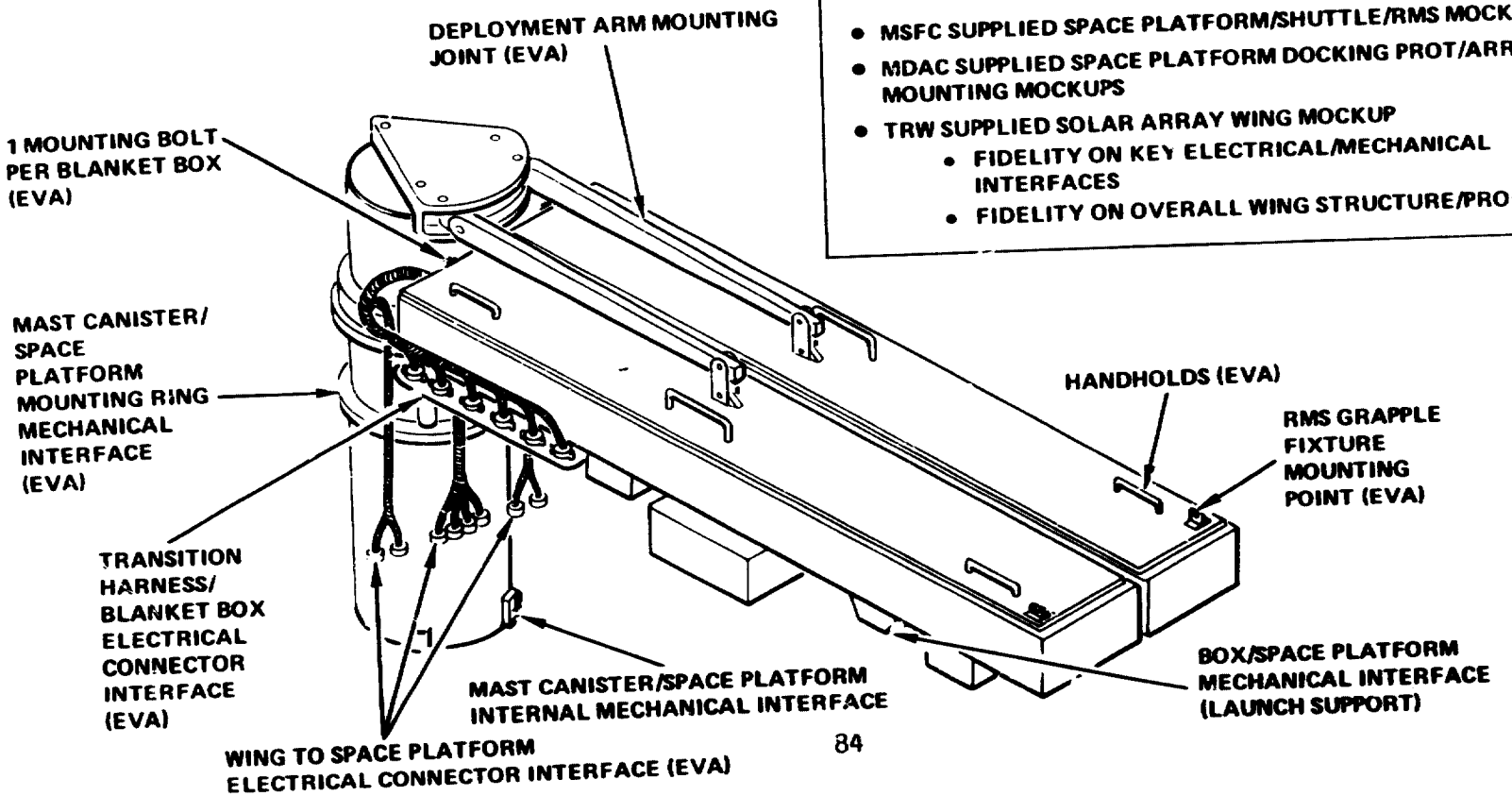
NEUTRAL BUOYANCY TEST

- TESTING OF THE SPACE PLATFORM SOLAR ARRAY WING/SPACE PLATFORM INTERFACES AND EVA PROVISIONS
- NEUTRAL BUOYANCY TEST IN THE MSFC NB FACILITY 15-24 NOVEMBER 1982
- TEST OBJECTIVE
  - DEMONSTRATE SPACE PLATFORM WING REPLACEMENT
  - DEMONSTRATE BLANKET BOX REPLACEMENT
- TESTING DONE IN CONJUNCTION WITH MDAC NBT SPACE PLATFORM TASK

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TEST HARDWARE

- MSFC SUPPLIED SPACE PLATFORM/SHUTTLE/RMS MOCKUPS
- MDAC SUPPLIED SPACE PLATFORM DOCKING PROT/ARRAY MOUNTING MOCKUPS
- TRW SUPPLIED SOLAR ARRAY WING MOCKUP
  - FIDELITY ON KEY ELECTRICAL/MECHANICAL INTERFACES
  - FIDELITY ON OVERALL WING STRUCTURE/PROFILE



SPACE STATION ROLE IN TDM MISSION IMPLEMENTATION

This chart presents a breakdown of the SS resources, attributes and capabilities involved in, or required for the servicing activities that are to be performed in each of the five selected example TDMs. Dark circles indicate major dependence, open circles moderate dependence (or interaction) of these TDM activities on (or with) the SS resources and features.

The purpose of the chart is to exhibit the degree by which each of the TDMs interact with the SS, as a further check on the suitability of our TDM selection. A high degree of TDM dependence/ interaction in most of the SS capability columns indicates a comparatively high level of mission complexity (and vice versa) and also tends to justify the selection in terms of the multiple SS capabilities and functions that will be exercised by that mission.

SPACE STATION ROLE IN TDM MISSION IMPLEMENTATION

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TDM CATEGORY	SELECTED EXAMPLE TDM / MSS RESOURCES ATTRIBUTES AND CAPABILITIES	STABLE CONSTRUCTION AND OPERATION PLATFORM	PERMANENT PRESENCE	LOGISTICS AND SUPPLY BASE (FOCUSES STS TRAFFIC)	LARGE STORAGE DEPOT (INCL PROPELLANTS)	EXPANDED CREW SIZE, LONG-DURATION HABITAT	INCREASED POWER CAPACITY	LARGE COMPUTER AND DATA MGT CAPACITY	TEST FACILITY AND SUPPORT EQUIPMENT	PROVIDES COORBITING SPACE PLATFORM FACILITIES	TMS/OTV OPERATIONS BASE
I	1. SS – BUILDUP BY MANIPULATOR INSTALLATION*	●	●	●	●	●	○	○	○		
II	2. SATELLITE ASSEMBLY, TEST AND LAUNCH	●	○	●	●	●	○	●	●		○
II	3. LARGE ANTENNA CONSTRUCTION AND TEST	●	○	○	○	●	○	●	●	○	
III	4. SERVICING GRO SPACECRAFT	○	●	○	●	●	○	●	●		●
III	5. SERVICING MATERIALS PROCESSING PLATFORM	○	●	●	●	○		○		●	●

LEGEND

* IN THIS TDM THE SPACE STATION IS ALSO THE PRIME OBJECT OF SERVICING ACTIVITY

● MAJOR DEPENDENCE
○ MODERATE DEPENDENCE
} ON MSS CAPABILITIES/RESOURCES

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ACCOMMODATION OF SERVICING NEEDS BY THE SPACE STATION

Satellite servicing will be a principal objective of most space station activities, and hence, servicing accommodation requirements of, and interfaces with hardware and software elements used in the TDMs have a major impact on both the space station evolution and projected TDM scenarios. The chart lists various factors involved in defining these accommodation requirements.

A summary of accommodation requirements and interfaces in terms of power, crew time, number of servicings, internal volume and number of SS attach points (or docking ports) used during servicing operations will be included in the detailed discussion of each of the five TDMs selected for further study. (Section 2, Appendix B and Appendix C).

ACCOMMODATION OF SERVICING NEEDS BY THE SPACE STATION

ACCOMMODATION REQUIREMENTS AND EQUIPMENT NEEDS DEPEND ON SEVERAL FACTORS:

- USER REQUIREMENTS
  - NASA SCIENCE AND APPLICATIONS SATELLITES
  - COMMERCIALLY OWNED SATELLITES
  - DOD SATELLITES
- TIME PHASING - WHEN IS THE EQUIPMENT REQUIRED?
- TECHNOLOGY DEVELOPMENTS
- TYPE OF SERVICING - MISSION OBJECTIVES
- COMMONALITY OF EQUIPMENT USE
- CREW TIME ALLOCATION, TRAINING, SUPPORT EQUIPMENT REQUIRED
- EQUIPMENT DEVELOPMENT COST AND SCHEDULE

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TDM CONCEPTUAL DESIGN GROUND RULES

The chart lists ground rules and guidelines adopted in defining TDM concepts, operating modes and equipment utlization. These ground rules apply broadly to the various TDM categories investigated. In addition, the specific TDM concepts selected for further study impose individual constraints and operating preferences such as the following:

TDM 1 (SS Manipulator Track Installation)	-	• Utilization of Orbiter RMS in handling of structural material • Efficient use of orbiter payload bay volume for carrying building materials
TDM 2 (Spacecraft Assembly, Test and Launch)	-	• Use of automated test sequences • Path finder assembly procedures demonstrated on ground
TDM 3 (Large Antenna Structure Deployment)	-	• Investigate space-deployable and erectable structure concepts • Consider transfer of deployed and tested antenna to a free flying satellite for operational mission use
TDM 4 (GRO Servicing and Refurbishment)	-	• Include installation of new payload sensors among servicing objectives • Utilize TMS for retrieval and redeployment of GRO
TDM 5 (Servicing of Free-Flying Materials Processing Platform)	-	• Restrict remote servicing by TMS to exchange of entire payload modules • Include periodic reboost of free-flying platform among servicing operations

TDM CONCEPTUAL DESIGN GROUND RULES

- USE BUILDING BLOCK APPROACH
- MINIMIZE EARLY YEAR COSTS
- EMPHASIZE TEST BED ROLE OF EARLY SPACE STATION
- EVOLVE MULTIPURPOSE TDMS THAT UTILIZE THE FULL RANGE OF SPACE STATION CAPABILITIES
- PAY CAREFUL ATTENTION TO THE ROLE OF THE CREW VERSUS AUTOMATION
- ENSURE EASY-TO-IMPLEMENT INTERFACES: ELECTRICAL, MECHANICAL, THERMAL (FLUID/GAS)
- ENSURE SAFE AND NON-CONTAMINATING EVENT SEQUENCES

TASK 1 - SUMMARY AND CONCLUSIONS

With the completion of Task 1, servicing technology requirements were established, a time-phased evolutionary technology plan was defined and TDM mission objectives and requirements were identified. The results provide inputs for more detailed TDM definition and analysis under Study Tasks 2 and 3.

Principal conclusions included the following:

- Most TDMs can be designed to demonstrate several satellite servicing technologies at the same time
- Investigation of earlier satellite servicing user model (SSUM)* keyed to STS use reveals many servicing missions that can be absorbed by the SS
- The shuttle serves as precursor in servicing technology development and will continue to complement SS servicing because of its launch/mission profile flexibility
- Crew capabilities and crew support provisions play a key role in the evolution of satellite servicing technology in the space station era

*"Satellite Services Study" Grumman contractual study for NASA/JSC (1979 to 1981)

TASK 1 - SUMMARY AND CONCLUSIONS

- ANALYZED SATELLITE SERVICING TECHNOLOGY REQUIREMENTS AND DEFINED TECHNOLOGY EVOLUTION PLAN (TASK 1.1)
- DEFINED TDM OBJECTIVES AND REQUIREMENTS (TASKS 1.2, 1.3) IN THREE PRINCIPAL CATEGORIES:
  - SS BUILD-UP/MODIFICATION
  - SATELLITE ASSEMBLY, TEST AND DEPLOYMENT
  - SATELLITE REFURBISHMENT AND REPAIR
- LISTED 25 CANDIDATE TDMs IN THESE CATEGORIES WITH THEIR MISSION OBJECTIVES AND REQUIREMENTS
- DEFINED TDM SELECTION CRITERIA
- SELECTED FIVE PRIORITY TDMs FOR FURTHER STUDY IN TASK 2 ON BASIS OF THESE CRITERIA
- EFFORT WAS FOCUSED ON TDMs THAT COMBINE TECHNOLOGY DEVELOPMENT/DEMONSTRATION WITH OPERATIONAL MISSION OBJECTIVES

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Task 2 Mission Definition

TASK 2 MISSION DEFINITION

This section of the final report is organized as shown by this chart. The Introduction and Summary first briefly repeats the scope, flow and output of Task 2 as outlined in the study plan. Tasks 2.2 and 2.3 are then treated together, presenting study results TDM by TDM. In this way each TDM is presented on a stand alone basis. Task 2.1 "TDM Conceptual Design" is reported as part of Task 1.

TASK 2 INTRODUCTION AND SUMMARY

TASK 2.1 TDM CONCEPTUAL DESIGN

TASK 2.2 TDM OPERATIONS ANALYSIS

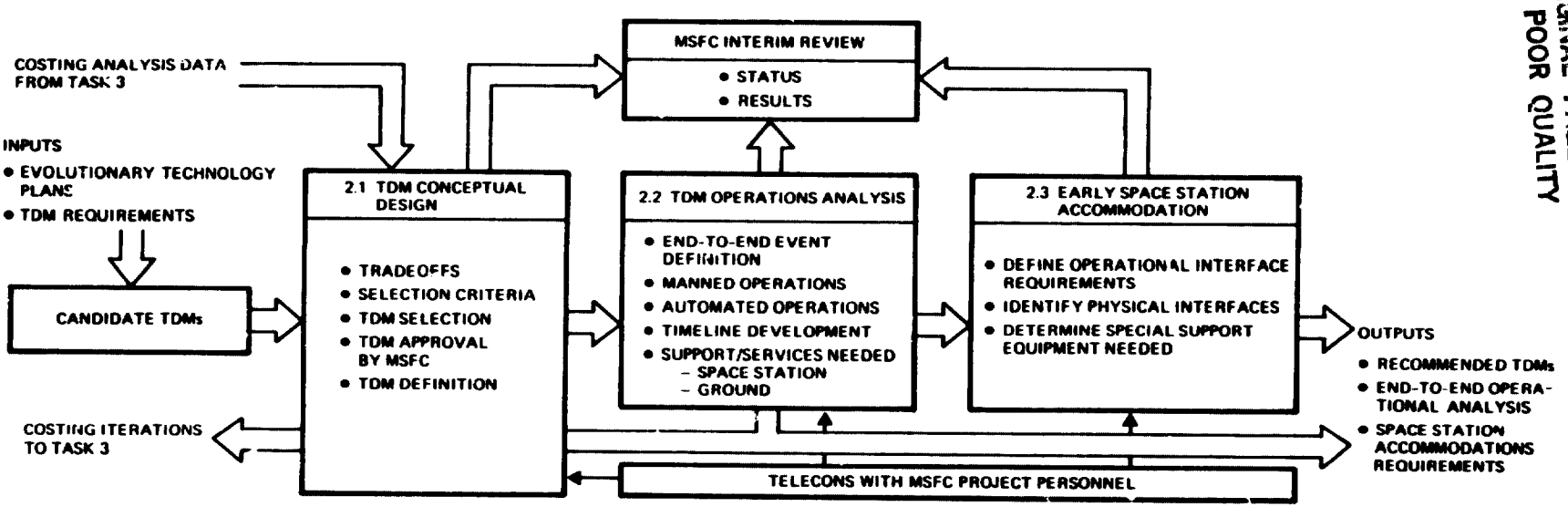
TASK 2.3 EARLY SPACE STATION ACCOMMODATION

TASK 2 MISSION DEFINITION - LOGIC FLOW

This chart presents the Task 2 logic flow. The task is divided into three major subtasks: 1) conceptual design, 2) operations analysis and 3) early space station accommodation. Conceptual design is intimately related to Task 1 where candidate TDMs were established. In fact, Task 1 actually developed the general trades and selection criteria by which the candidate TDMs in each of the three categories were evaluated. For these reasons Task 2.1 "TDM Conceptual Design" is reported as part of Task 1. Tasks 2.2 "TDM Operations Analysis" and Task 2.3 "Early Space Station Accommodation" are reported in this section. The Task 2.2 operations analyses for each TDM are done at two levels: 1) at a summary or overview level and 2) at a detail step-by-step level. This step-by-step detailing produces the preliminary timeline. From this detailing also is derived the identification of manned involvement, automation requirements and support services required - both ground and space station (Task 2.3). The product of this task is sufficient information in the form of timelines, interface identification and special requirements to support the scheduling and costing of Task 3.

TASK 2. MISSION DEFINITION - LOGIC FLOW

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TASK 2 MISSION DEFINITION SUMMARY

This chart, from the Study Plan, provides further detail of the flow of Task 2. The output of the mission definition is a set of descriptive information for each of the five TDMs selected for detailed definition. Again, as discussed in the preceeding facing page, Task 2.1 "TDM Conceptual Design" is folded into Task 1 "Mission Requirements."

TASK 2. MISSION DEFINITION - SUMMARY

SUBTASK OBJECTIVES	INPUTS	APPROACH	EXPECTED OUTPUTS
2.1 TECHNOLOGY DEVELOPMENT MISSION (TDM) CONCEPTUAL DESIGN • DEFINITION OF TDM(S) FOR EARLY MANNED SPACE STATION	TDM OBJECTIVES AND REQUIREMENTS	1. PERFORM REQUIREMENTS ANALYSIS 2. GENERATE CANDIDATE TDMs 3. PERFORM TRADE STUDIES 4. DEVELOP AND APPLY SELECTION CRITERIA 5. SELECT THE RECOMMENDED TDMs; OBTAIN MSFC CONCURRENCE IN SELECTION 6. CONCEPTUALLY DESIGN SELECTED TDMs	SATELLITE SERVICING TDMs FOR INPUT TO TASK 3 AND SUBTASKS 2.2 AND 2.3
2.2 TDM OPERATIONS ANALYSIS • END-TO-END OPERATIONS ANALYSIS OF EACH SELECTED TDM • REQUIREMENTS THAT INDIVIDUAL MISSIONS COLLECTIVELY LEVY ON EARLY MANNED SPACE STATION	TDMs FROM SUBTASK 2.1	1. REVIEW EACH TDM DESIGN CONCEPT 2. PERFORM END-TO-END OPERATIONS ANALYSIS OF EACH TDM 3. GENERATE INTEGRATED SPACE STATION REQUIREMENTS	OPERATIONS ANALYSIS REPORT FOR EACH TDM, AN INTEGRATED SET OF OPERATIONAL AND DESIGN REQUIREMENTS IMPOSED BY TDMs ON EARLY SPACE STATION
2.3 ACCOMMODATION NEEDS FROM AN EARLY SPACE STATION • CONCEPTUAL DEFINITION OF SPECIAL SUPPORT EQUIPMENT NEEDED ON THE EARLY SPACE STATION FOR SATELLITE SERVICING	SERVICING SUPPORT REQUIREMENTS FROM SUBTASK 2.2	1. CATEGORIZE EQUIPMENT REQUIREMENTS 2. ASSOCIATE REQUIREMENTS WITH EQUIPMENT FOR EARLY AND GROWTH VERSIONS OF SPACE STATION 3. PRIORITIZE EQUIPMENT FOR EARLY SPACE STATION 4. CONCEPTUALLY DEFINE EQUIPMENT FOR SPACE STATION	CONCEPTUALLY DEFINED SPECIAL EQUIPMENT AND TIME-PHASING REQUIRED FOR SPACE STATION TO SUPPORT ON-ORBIT SATELLITE SERVICING

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TASK 2.2 TDM CONCEPTUAL DESIGN AND TASK 2.3 EARLY SPACE STATION ACCOMMODATION

These two subtasks of Task 2 Mission Definition are combined and reported together for each of the five TDMs being defined in detail.

TASK 2 INTRODUCTION AND SUMMARY

TASK 2.1 TDM CONCEPTUAL DESIGN*

TASK 2.2 TDM OPERATIONS ANALYSIS

TASK 2.3 EARLY SPACE STATION ACCOMMODATION

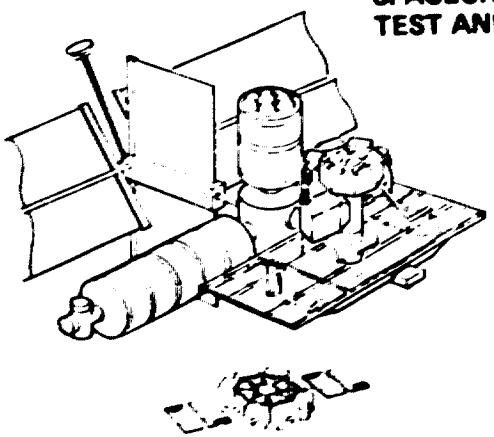
*REPORT OF TASK 2.1 FOLDED INTO THE REPORT OF TASK 1

SATELLITE SERVICING STUDY TDMS (OVERVIEW)

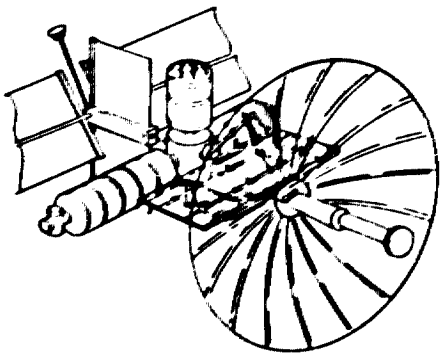
The five TDM types selected for more detailed study are shown here by outline sketches to illustrate some salient points. In three of these missions dealing with assembly, deployment or refurbishment/repair of satellites or space structures (TDM 2, TDM 4 and TDM 3, respectively) an early space station configuration is assumed of the type identified in TRW's concurrent Space Station Concepts and Architectural Options study. These configurations provide the necessary resources to support/accommodate the TDMs in question. The manipulator track installation, TDM 1, is shown on a reconfigured space station, with the shuttle orbiter at one of the available berthing ports supporting the construction task. The illustration of TDM 5, servicing of a free-flying materials processing platform with the aid of the teleoperator (TMS), only shows that platform and the TMS approaching it for removal/replacement of a sample magazine or payload module. The concept shown here derives from TRW's earlier (1979-1981) conceptual design studies of a 25 kW Space Platform and of a Materials Experiment Carrier (MEC) attached to that platform. Both studies were performed under NASA/MSFC contracts (NAS8-33956 and NAS8-33688).

Subsequent sections will address the implementation, mission sequences, scenario highlights, interfaces and support requirements, precursor missions, and overall mission benefits of each of these TDMs in some detail.

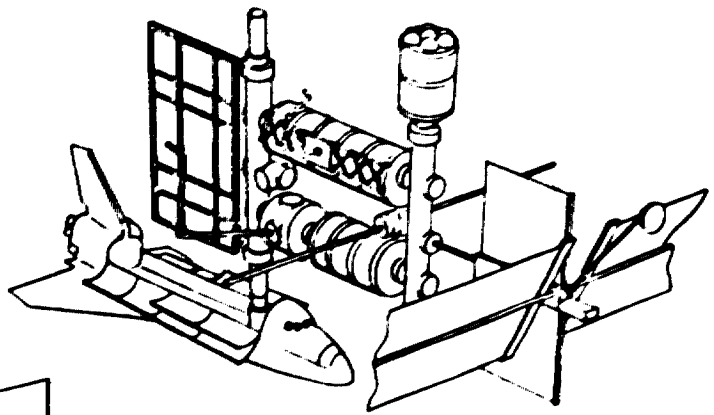
SATELLITE SERVICING STUDY TDMs



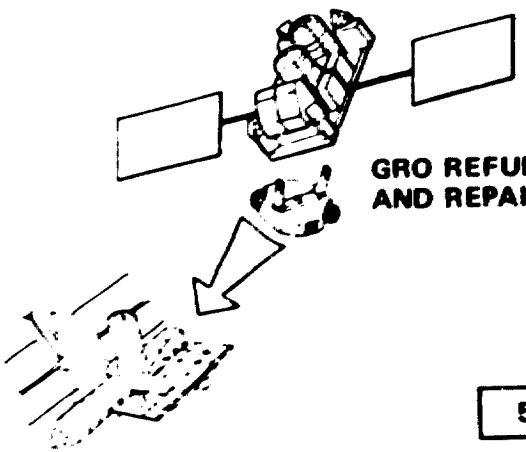
SPACECRAFT ASSEMBLY, TEST AND LAUNCH



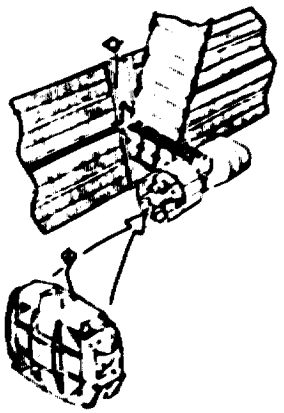
LARGE ANTENNA STRUCTURE DEPLOYMENT



SS MANIPULATOR TRACK INSTALLATION



GRO REFUELING AND REPAIR



SERVICING OF FREE-FLYING MATERIALS PROCESSING PLATFORM

5 TDM's SELECTED FROM 25 CANDIDATES

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TASK 2.2 AND TASK 2.3

Task 2.2 and Task 2.3 are further subdivided as shown on this chart. Task 2.2 covers end-to-end event definition, timelines and support services. Task 2.3 covers interfaces and support equipment. This section of the final report addresses each of these items TDM by TDM.

TASK 2.2 AND TASK 2.3

- SUBTASKS AND SUBTASK TOPICS COVERED FOR EACH TDM

TASK 2.2 TDM OPERATIONS ANALYSIS	TASK 2.3 EARLY SPACE STATION ACCOMMODATION
-- END-TO-END EVENT DEFINITION	-- INTERFACES
-- TIMELINES (PRELIMINARY)	-- SUPPORT EQUIPMENT
-- SUPPORT SERVICES NEEDED	

- TDM ADDRESSED ON THE FOLLOWING PAGES

TDM 1 BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY

TDM 2 ON-ORBIT SPACECRAFT ASSEMBLY, TEST AND LAUNCH

TDM 3 LARGE ANTENNA STRUCTURE DEPLOYMENT

TDM 4 SERVICE/REFURBISH SATELLITE (GRO)

TDM 5 SERVICING OF FREE-FLYING MATERIALS PROCESSING PLATFORM

SATELLITE SERVICING - TDM 1 SUMMARY BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY

TDM 1 involves the construction of a track system to support a movable manipulator arm on the early space station. A fixed manipulator arm is assumed to be in place prior to the start of this mission. The track system is assembled on-orbit from small parts delivered via STS. A later STS assists in transferring the space station RMS to the track system, using the STS RMS.

This TDM affords the opportunity to perform significant construction and assembly types of operations on the space station. These operations all both add to the capability of the space station and form an experience base for similar future operations on the space station and in space generally.

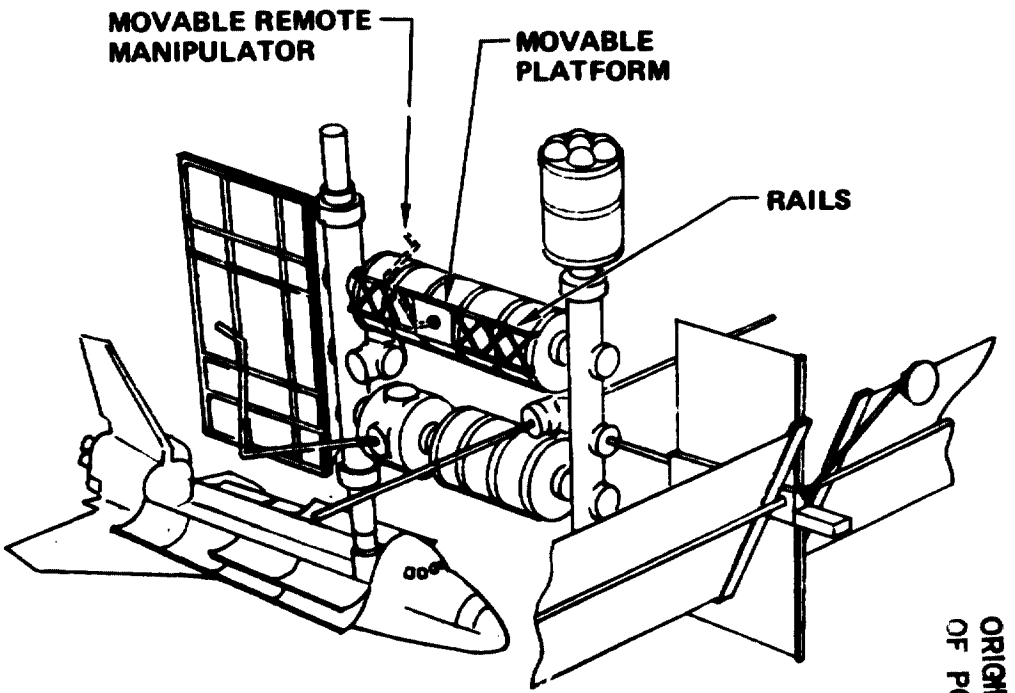
The technology development areas listed on this chart identify broad technology areas involved in this mission. Specific lower-level technology development elements with identified precursors are listed on the second chart following.

SATELLITE SERVICING - TDM #1 SUMMARY
BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY

TRW

1. TECHNOLOGY DEVELOPMENT AREAS
   - LARGE STRUCTURE ASSEMBLY IN SPACE
   - ADVANCED EVA TECHNOLOGIES
   - ADVANCED CREW SUPPORT SYSTEMS
   - ADVANCED MANIPULATOR USES
   - ON ORBIT SYSTEM/SUBSYSTEM TEST
   - SPACE STATION INSTALLATIONS

2. BENEFITS
   - DEVELOP ON ORBIT ASSEMBLY TECHNIQUES
   - ENHANCE SS LOAD HANDLING CAPABILITY
   - SUPPORT SUBSEQUENT SS MODIFICATIONS



3. SPACE STATION REQUIREMENTS SUMMARY
   - STORAGE PROVISIONS ON SS FOR BUILDING MATERIALS
   - SPECIAL CREW TRAINING, PROCEDURES
   - SPECIAL CREW SUPPORT EQUIPMENT, INSTALLATION TOOLS
   - AUTONOMOUS MISSION SUPPORT SYSTEMS

4. SCENARIO HIGHLIGHTS
   - SHUTTLE DELIVERS RMS, RAILS AND OTHER BUILDING MATERIAL
   - SHUTTLE RMS ASSISTS EVA CREW IN CONSTRUCTION
   - CREW COMPLETES INSTALLATION, PERFORMS CHECKOUT AND FUNCTIONAL TESTS

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TDM 1

MISSION SEQUENCE

BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY

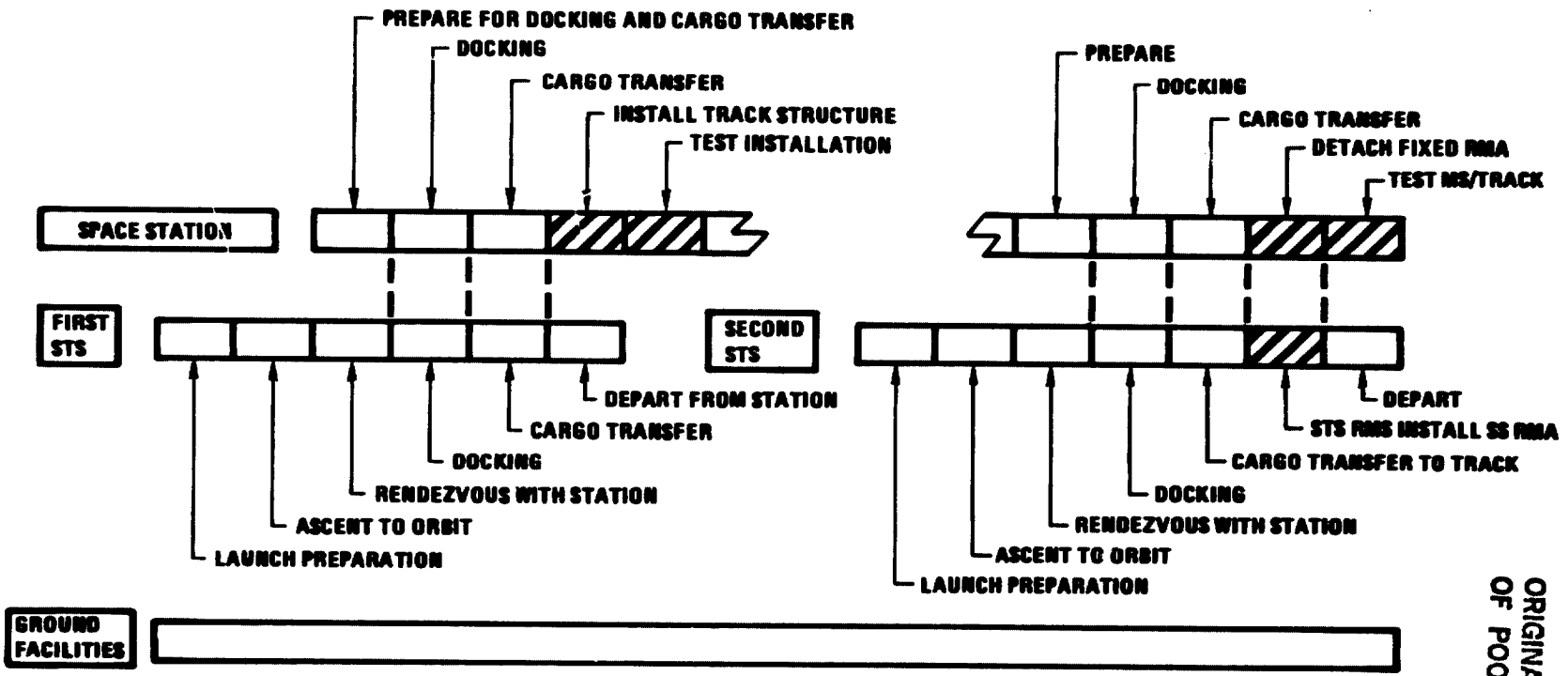
This diagram shows the time sequencing of the major phases of this TDM. Phases for the space station, the STS, and the ground facilities are shown as separate horizontal bars. Those phases which must be synchronized between different elements are connected with dashed lines. This chart shows time sequencing, but does not show duration (each phase is shown as the same length, although they differ widely in duration).

The key feature of this TDM is the indefinite time elapsed between the first and second STS missions. The space station astronauts can take as much time as needed to assemble and test the track structure. The second STS flight can be scheduled when these non time critical tasks are completed.

Another key element of this TDM is the relative autonomy of operations from detailed ground direction and control. Ground facility involvement in detailed operations should only be required in the event of anomalies.

The crosshatched phases are those peculiar to this TDM. These phases are further detailed in the following charts.

TDM 1 MISSION SEQUENCE BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY



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TDM 1 TASK DETAIL

This chart displays the detailed task breakdown of the first two unique TDM 1 mission phases, namely Install Track Structure and Test Track Installation. The tables identify each task, and estimate the resources and time required for accomplishment. Because of limitations on EVA time and the necessity for fitting these tasks into the space station overall schedule, the sum of the track times is not to be thought of as total phase duration. Fitting the tasks into an overall timeline remains to be done.

Install Track Structure

This task is relatively labor intensive in that the track structure is assembled from a large number of relatively small members ($\sim$ 5 ft). Because this task is non-time critical, as described in a previous chart, the EVA construction can be done as a "background" task when other EVA tasks are scheduled.

Test Track Installation

When installation of the external structure and internal equipment is completed, diagnostic tests are run. The internal equipment includes a test set which automates these diagnostic tests as much as feasible.

TDM-1 TASK DETAIL

INSTALL TRACK STRUCTURE TEST TRACK INSTALLATION

INSTALL TRACK STRUCTURE

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME
OPEN PACKING CONTAINER	1		YES			.4
[1] UNPACK MEMBER (.1)	1		YES			
[2] TRANSFER TO LOCATION (.1)	1		YES			
[3] FASTEN IN PLACE (.1)	1		YES			
REPEAT [1]-[3] APPROXIMATELY 70 TIMES						21
UNPACK RM RM TRACK PLATFORM	2		YES			.3
TRANSFER TO TRACK		YES				.2
INSTALL TO TRACK	2		YES			.5
UNPACK CABLING AND FITTINGS	2		YES			.5
INSTALL CABLING	2		YES			4
UNPACK SS INTERNAL EQUIPMENT	2		YES			.3
TRANSFER INTO SS	2					.3
INSTALL SS INTERNAL EQUIPMENT						4
				TOTAL HOURS		31.5

TEST TRACK INSTALLATION

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
RUN DIAGNOSTICS WITH SS INTERNAL EQUIPMENT						.2
COMMAND FULL RANGE OF MOTION OF TRACK PLATFORM						.5
REPEAT DIAGNOSTICS						.2
				TOTAL HOURS		.9

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TDM 1 TASK DETAIL

The three tasks detailed on this chart, detach fixed RMA, STS RMS install SS RMA, and test MS/track, are those accomplished after the second STS delivery.

Detach Fixed RMA

This task is accomplished by EVA astronauts when the second shuttle is ready to assist in transferring the space station RMA to the track platform.

STS RMS Install SS RMA

The shuttle RMS is used to move the disconnected RMA to the track platform for installation. It would be possible for EVA astronauts to accomplish this, but use of the RMS is safer for an object of this size and mass.

Test MS/Track

When the installation is complete, the mobile RMA is tested. The space station internal equipment is designed to carry out comprehensive testing of the system with no EVA required.

TDM-1 TASK DETAIL
DETACH FIXED RMA
STS RMS INSTALL SS RMA; TEST MS/TRACK

DETACH FIXED RMA

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
PLACE FIXED RMA IN STOWED POSITION		YES				.1
TETHER RMA	1					.2
DISCONNECT CABLING	1					.4
MECHANICAL DISCONNECT	1					.4
				TOTAL HOURS		1.1

STS RMS INSTALL SS RMA

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
GRAPPLE STOWED RMA		STS				.1
DETACH TETHER	1					.2
TRANSLATE TO TRACK PLATFORM		STS				.2
MECHANICAL CONNECTION	1					.4
CABLE CONNECTION	1					.4
RETRACT STS RMA		STS				.1
				TOTAL HOURS		1.4

TEST MS/TRACK

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
RUN DIAGNOSTICS WITH SS INTERNAL EQUIPMENT						.2
COMMAND FULL RANGE OF RMA MOTION		YES				.5
COMMAND FULL RANGE OF TRACK MOTION		YES				.5
REPEAT DIAGNOSTICS						.2
				TOTAL HOURS		1.4

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KEY TDM PRECURSORS - TDM 1 BUILDUP OF SS MANIPULATOR CAPABILITY

The five TD elements identified in this chart have ground-based and orbiter-based precursors. Precursor activities on the ground include modeling and simulation of large structure assembly, use of the remote manipulator (RMS), and crew performance observations in underwater tests. Of particular interest in these and other precursor activities is the use of heads-up displays (HUD) for more efficient, time saving and error free crew operations. Performing similar tasks on-board the shuttle orbiter will verify and demonstrate the techniques initially evolved on the ground and will increase confidence in successful and efficient handling of comparable tasks in subsequent space station missions.

Careful preparation and performance of precursor activities for each TD element on the ground and on-orbit will be a key to achieving a successful TDM on-board the space station and thus lead the way to cost and time efficient utilization of the SS in the complex construction tasks of the type involved in TDM 1.

KEY TDM PRECURSORS - TDM 1
BUILDUP OF SS MANIPULATOR CAPABILITY

TECHNOLOGY DEVELOPMENT ELEMENT	(A) GROUND PRECURSOR	(B) STS PRECURSOR	STATUS
1. LARGE STRUCTURE ASSEMBLY	• MODELING AND SIMULATION • UNDERWATER TESTS	• DEMONSTRATION OF ASSEMBLY TECHNIQUES ON ORBITER, e.g., STRUCTURAL ASSEMBLY DEMONSTRATION EXPERIMENT (SADE)	(B) PROJECTED ~ 1985
2. UTILIZATION OF RMS WITH CHERRY PICKER	• SIMULATION INCLUDING CREW TASK HANDLING	• DEMONSTRATION ON ORBITER	(B) PROJECTED START 1984 (SOLAR MAX)
3. RMS MANIPULATION OF LARGE PAYLOAD	• SIMULATION • RMS ENGINEERING SIMULATOR EXPERIMENTS	• HANDLING OF LDEF	(B) PROJECTED 1984
4. MULTIPLE RMS OPERATION IN P/L HANDLING/POSITIONING	• SIMULATION • RMS ENGINEERING SIMULATOR EXPERIMENTS	• DEMONSTRATION ON ORBITER	CONCEPT
5. UTILIZATION OF HUD[1]	• CREW PERFORMANCE MEASUREMENT ON VARIOUS HUD IMPLEMENTATIONS	• DEMONSTRATE HUD ON OPERATIONAL EVA TASKS IN ORBITER BAY	CONCEPT

[1]HUD – HEADS UP DISPLAY IN ASTRONAUT EMU HELMENT

TDM 1 MISSION INTERFACES AND SUPPORT REQUIREMENTS

This chart lists the major operational and physical interfaces for space station support of this mission. None of these interfaces are peculiar to this mission; they are all generic to the operation of the space station.

Also listed are the support services and equipment required for this mission. These services and equipment are peculiar to this mission, and thus must be included in the mission costs.

Appendix B and C contain additional detail of requirement.

TDM 1 MISSION INTERFACES AND SUPPORT REQUIREMENTS

TRW

	SPACE STATION	OTHER (NON SS)	MISSION PECULIAR	ASSUMED GENERIC
OPERATIONAL INTERFACE:				
SHUTTLE DOCKING AND CARGO TRANSFER	●			●
VICEO AND VOICE COMMUNICATION WITH GROUND FACILITIES	●			●
PHYSICAL INTERFACE:				
SHUTTLE/SPACE STATION DOCKING FACILITY	●			●
CARGO TRANSFER FACILITIES	●			●
CARGO STORAGE FACILITIES	●			●
COMMUNICATIONS LINKS TO GROUND FACILITIES	●			●
SUPPORT SERVICES:				
DESIGN AND MANUFACTURE TRACK STRUCTURE AND CONTROL SYSTEM		●	●	
CREATE DETAILED PROCEDURES FOR ON-ORBIT CONSTRUCTION OPERATIONS		●	●	
MONITOR ON-ORBIT OPERATIONS AND RESOLVE ANOMALIES		●		●
SUPPORT EQUIPMENT:				
SPECIAL PACKING CONTAINERS		●	●	
SPECIAL ASSEMBLY TOOLS	●		●	
TRACK SYSTEM TEST SET	●		●	
MISSION PECULIAR GROUND FACILITY SOFTWARE AND PROCEDURES		●	●	

KEY BENEFITS OF TDM 1 BUILDUP OF SS MANIPULATOR CAPABILITY

The overall benefit of this TDM is enhancement of SS operational capability and flexibility, as well as aid to its evolutionary growth. The RMA, movable on tracks for increased access to construction sites and payload locations on the space station, greatly increases its utility without requiring an enlargement of its own limited 15-meter reach envelope. The RMA thus can be used to aid in SS structural additions or modifications within a wide range of architectural choices. A second RMA installed on the same rail system would add to this flexibility and versatility.

The RMA when operating on the periphery of the space station can be used to advantage in thrust free satellite deployment via the gravity gradient separation mode. It also becomes a convenient capture and berthing arm for incoming OTVs or the shuttle orbiter.

The chart lists-five TD elements and their benefits in the evolution and growth of the space station itself and in enhancing its utility of supporting satellite launch and repair/refurbishment activities. A principal benefit is the increased support the movable RMA provides to EVA crew operations, including use of the open cherry picker.

KEY BENEFITS OF TDM 1
BUILDUP OF SS MANIPULATOR CAPABILITY

TECHNOLOGY DEVELOPMENT ELEMENT	MISSION BENEFIT(S)
1. LARGE STRUCTURE ASSEMBLY	• USERS IN ERA OF LARGE SCALE CONSTRUCTION JOBS ON SS • RAIL SYSTEM INCREASES RMS ACCESS AND REACH, ENHANCES FLEXIBILITY OF OPERATIONS
2. UTILIZATION OF RMS WITH CHERRY PICKER	• ENHANCES CREW CAPABILITY AND OPERATING MODES • ENHANCES SAFETY OF RMS OPERATIONS REMOTE FROM CONTROL STATION
3. RMA MANIPULATION OF LARGE PAYLOAD	• FACILITATES SATELLITE ASSEMBLY • ESSENTIAL TO MSS RECONFIGURATION TASKS • ESSENTIAL TO BERTHING OF RETRIEVAL SATELLITES, TMS, OTV; ALSO FACILITATES ORBITER BERTHING • PERMITS THRUST-FREE SATELLITE DEPLOYMENT VIA GRAVITY GRADIENT MODE • CONTROL DYNAMICS DEMONSTRATION
4. MULTIPLE RMA OPERATION	• INCREASED P/L HANDLING FLEXIBILITY AND CONTROL
5. UTILIZATION OF HUD IN EVA TASKS	• ENHANCES CREW PRODUCTIVITY/EFFECTIVENESS, SAVES TIME AND TRAINING COST • REDUCES HUMAN ERROR RISK • ENHANCES CREW SAFETY

OVERALL TDM BENEFIT – ENHANCES SS OPERATION CAPABILITY AND FLEXIBILITY AND AIDS SS EVOLUTIONARY GROWTH

TASK 2.2 AND TASK 2.3

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- SUBTASKS AND SUBTASK TOPICS COVERED FOR EACH TDM

TASK 2.2 TDM OPERATIONS ANALYSIS	TASK 2.3 EARLY SPACE STATION ACCOMMODATION
-- END-TO-END EVENT DEFINITION	-- INTERFACES
-- TIMELINES (PRELIMINARY)	-- SUPPORT EQUIPMENT
-- SUPPORT SERVICES NEEDED	

- TDM ADDRESSED ON THE FOLLOWING PAGES

TDM 1 BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY

TDM 2 ON-ORBIT SPACECRAFT ASSEMBLY, TEST AND LAUNCH

TDM 3 LARGE ANTENNA STRUCTURE DEPLOYMENT

TDM 4 SERVICE/REFURBISH SATELLITE (GRO)

TDM 5 SERVICING OF FREE-FLYING MATERIALS PROCESSING PLATFORM

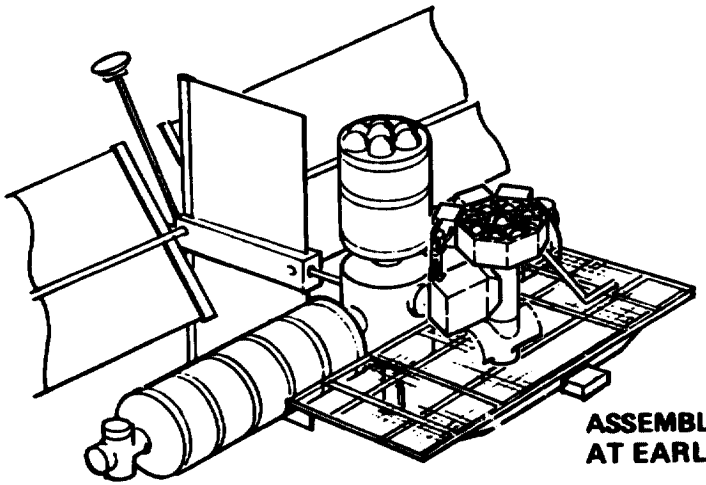
This TDM involves the on-orbit assembly, test, fueling, and launch of a modular spacecraft that may exceed the weight or volume capacity of a single shuttle launch or which has purposely been designed to be carried to orbit partially assembled. Many on-orbit operations are touched by this TDM including particularly those also directly related to servicing such as ORU installation, inspection, deployment of appendages, propellant loading, checkout, and launching from a space station.

This mission is particularly suited for the space station because of the time required to complete all procedures, and because of the storage, power, and other support facilities required.

SATELLITE SERVICING - TDM #2 SUMMARY ON-ORBIT SPACECRAFT ASSEMBLY, TEST AND LAUNCH

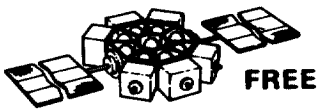
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1. TECHNOLOGY DEVELOPMENT AREAS
   - EVA TECHNOLOGIES
   - ON ORBIT SPACECRAFT ASSEMBLY
   - ON ORBIT REFUELING
   - ON ORBIT SYSTEM/SUBSYSTEM TEST
   - RMA HANDLING METHODOLOGIES



ASSEMBLY & FINAL TEST AT EARLY SPACE STATION

2. BENEFITS
   - FINAL TEST ON ORBIT IMPROVES PROBABILITY OF MISSION SUCCESS
   - SPACECRAFT MAY EXCEED STS SIZE AND WEIGHT LIMITS



FREE FLYERS/PLATFORMS

3. SPACE STATION REQUIREMENTS SUMMARY
   - STORAGE PROVISIONS ON SPACE STATION
   - MODULE HANDLING BY RMS, AIDED BY CREW (EVA)
   - MECHANICAL AND ELECTRICAL FSE (GENERAL AND SPECIAL PURPOSE) NEEDED
   - SPECIALIZED CREW TRAINING, CREW SUPPORT EQUIPMENT
   - STANDARDIZED INTERFACE DESIGN
   - AUTONOMOUS MISSION SUPPORT SYSTEMS

4. SCENARIO HIGHLIGHTS
   - SPACECRAFT MODULES DELIVERED ON SUCCESSIVE SHUTTLE VISITS
   - STORED ON-BOARD SPACE STATION
   - ASSEMBLED, CHECKED-OUT, TESTED BY SS CREW, PARTLY IN EVA MODE
   - CREW ASSISTS IN APPENDAGE DEPLOYMENT
   - CREW PREPARES SPACECRAFT FOR AND ACCOMPLISHES LAUNCH

TDM 2

MISSION SEQUENCE

ON-ORBIT ASSEMBLY, TEST AND LAUNCH OF SPACECRAFT

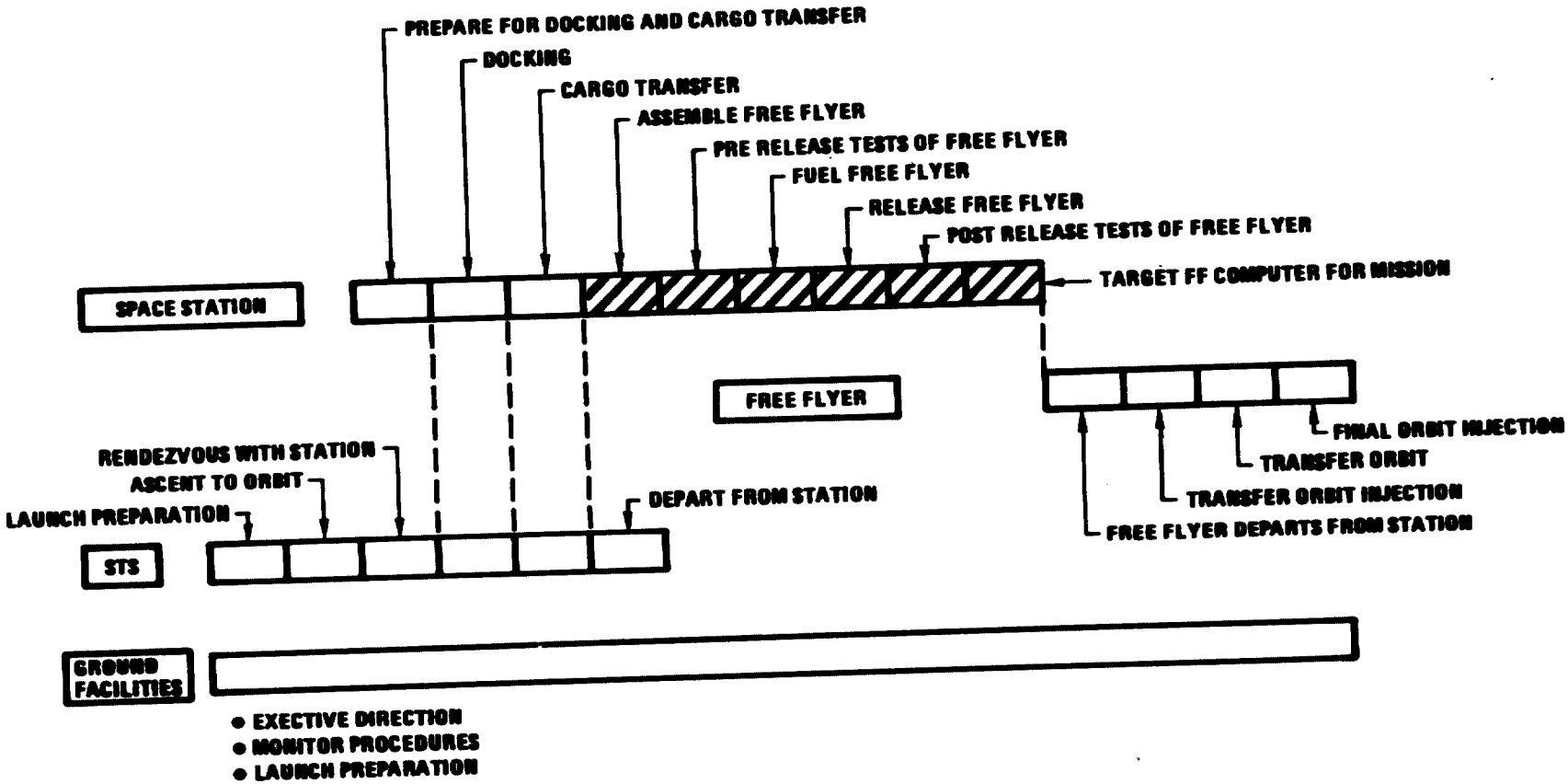
This sequence diagram is similar to the previous one during the STS operations. After STS departure, the assembly and test operations become non-time critical.

A key feature of this mission is the independence from the ground facilities of the targeting and launch of the free flyer spacecraft (barring anomalies). Because the launch of the spacecraft into its transfer orbit does not involve scheduling extensive facilities and large numbers of people, the launch date and time can be much less critical.

Because final spacecraft testing is done in orbit, and because transfer orbit injection can be delayed until all anomalies are resoved, probability of mission success will be improved.

The crosshatched phases are those peculiar to this TDM and these phases are further detailed in the following charts.

TDM 2 MISSION SEQUENCE ON-ORBIT ASSEMBLY, TEST AND LAUNCH OF SPACECRAFT



ASSEMBLE FREE FLYER

The assembly and partial test of the free flyer spacecraft is facilitated by the design of the spacecraft modules for rapid electrical and mechanical connection and by the provision of built-in, automated test equipment in each module.

All the times quoted in these charts assume no learning curve and no anomalies.

TDM-2 TASK DETAIL

ASSEMBLE FREE FLYER

TRW

ASSEMBLE FREE FLYER

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
OPEN MODULE PACKING CONTAINER	2		YES			.2
UNPACK ELECTRICAL POWER MODULE	1					.3
TRANSFER TO BUS		YES				.2
INSTALL EPM TO BUS	2	YES	MAYBE			.5
CONNECT STATION POWER AND DATA LINES	1					.5
ACTIVATE EPM AND TEST						1
UNPACK ATTITUDE CONTROL MODULE	1					.3
TRANSFER TO BUS		YES				.2
INSTALL ACM TO BUS	2	YES	MAYBE			.5
ACTIVATE ACM AND TEST						1
UNPACK COMMUNICATION AND DATA HANDLING MODULE	1					.3
TRANSFER TO BUS		YES				.2
INSTALL CDHM TO BUS	2	YES	MAYBE			.5
ACTIVATE CDHM AND TEST						2
UNPACK PAYLOAD MODULE	2		YES			.3
TRANSFER TO BUS		YES				.3
INSTALL PAYLOAD TO BUS	2	YES	MAYBE			.5
UNPACK ANTENNA MODULE	1					.5
TRANSFER TO BUS		YES				.2
INSTALL AM TO BUS	2	YES	MAYBE			.8
CONNECT RF ADAPTER TO BUS	1					.5
ACTIVATE SPACECRAFT TRANSMITTER AND TEST						2
DISCONNECT RF ADAPTER	1					.2
UNPACK SOLAR PANELS	1					.5
TRANSFER TO BUS		YES				.2
INSTALL SOLAR PANELS TO BUS	2	YES	MAYBE			1
DEPLOY SOLAR PANELS MANUALLY	2		YES			1
TEST GIMBALLING AND POWER GENERATION						2
	128			TOTAL HOURS		15.7

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After assembly and test, the spacecraft is prepared for launch. Open loop testing and fueling are performed.

Pre-Release Tests

The assembled spacecraft is open-loop tested using a test set and synthetic sensor signals. These tests verify the electromechanical performance of the spacecraft in a fixed position.

Fuel Free Flyer

The free flyer is fueled from a space station supply. Monopropellant is assumed. This is assumed to be an EVA activity. Current studies of on-orbit refueling of GRO may indicate changes to the procedures outlined here.

TDM-2 TASK DETAIL
PRE RELEASE TESTS
FUEL FREE FLYER

PRE RELEASE TESTS

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME
CONNECT TEST SET TO DRIVE OPEN LOOP TESTS						.5
VERIFY HARDLINE COMMAND-TELEMETRY LOOP THROUGH C&DH SUBSYSTEM						.5
CONNECT SUPPORT EQUIPMENT TO FF SENSORS	1					1
STIMULATE FF SENSORS USING SUPPORT EQUIPMENT						.5
VERIFY SYSTEM PERFORMANCE UNDER TEST CONDITIONS						1
				TOTAL HOURS		3.5

FUEL FREE FLYER (MONOPROPELLANT)

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME
CONNECT SUPPLY HOSE TO FF INTAKE VALVE	1					.5
BLEED FF TANK RESIDUAL PRESSURE	1					.2
CLOSE BLEED VALVE	1					.1
OPEN SUPPLY VALVE	1					.1
MONITOR FF TANK PRESSURE						.2
SHUTOFF SUPPLY VALVE WHEN DESIRED PRESSURE IS REACHED	1					.1
CLOSE FF TANK INLET VALVE	1					.1
BLEED SUPPLY HOSE	1					.1
DISCONNECT SUPPLY HOSE FROM FF AND STOW	1					.5
				TOTAL HOURS		1.9

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The testing performed after spacecraft release can be more complete and realistic

Release Free Flyer

The tested and fueled free flyer spacecraft is released from the space station assembly deck and command to depart to a safe distance, using low power thrusters.

An alternative way of accomplishing safe separation, before enabling the ACS, would be to use a TMS or possibly one or more MMUs.

Post Release Tests

With the spacecraft at a safe distance, the attitude control, propulsion, and RF systems can be enabled and their functioning verified by command.

The probability of mission success is increased by on-orbit integration and test because of the realism of the final post release test conditions and because the free flyer spacecraft can still be returned to the space station for corrective action if any anomoly develops during testing.

TDM-2 TASK DETAIL
RELEASE FREE FLYER
POST RELEASE TESTS

RELEASE FREE FLYER

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
DISCONNECT POWER AND DATA LINES	1					.5
DISCONNECT HOLD DOWNS	1					.5
REMOVE FROM STATION DECK AND RELEASE		YES				.5
ENABLE FREE FLYER ACS						.1
COMMAND FF TO DEPART TO SAFE DISTANCE						.1
				TOTAL HOURS		1.7

POST RELEASE TESTS

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
VERIFY RF COMMAND-TELEMETRY LOOP THROUGH C&DH SYSTEM						.5
VERIFY ATTITUDE CONTROL FUNCTIONING						.5
VERIFY ANTENNA PATTERNS						2
				TOTAL HOURS		3

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The assumption here is that the spacecraft will have onboard autonomous guidance and navigation, and that the targeting of the mission constants for the spacecraft guidance computer will be done in a special targeting computer on the space station.

Other assumptions are possible, such as guidance from a ground facility, or autonomous spacecraft guidance with ground targeting. On orbit mission targeting was chosen as a technology development.

TARGET FREE FLYER COMPUTER

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
CONTACT GROUND FACILITIES						.1
FINALIZE MISSION PLANNING						100
SET TIME FOR TRANSFER ORBIT INJECTION						.1
FF MISSION TARGETING CONSTANTS GENERATED						.1
TRANSMIT MISSION CONSTANTS TO FF AND VERIFY						.2
COMMAND ENABLE FF AUTONOMOUS GUIDANCE AND NAVIGATION						.1
				TOTAL HOURS		100.6

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KEY TDM PRECURSORS - TDM 2 ON-ORBIT SPACECRAFT ASSEMBLY, TEST AND LAUNCH

Seven technology development elements (TDEs) are identified for TDM 2 in this chart. Ground-based precursor tasks are listed for four of the TDEs, while shuttle-based precursors are listed for all. Underwater tests will be used to evolve and demonstrate crew procedures. Other ground tests, to be performed on the air bearing simulator, will demonstrate operation of the open cherry picker. As in TDM 1, the use of HUD techniques will be refined on the ground in preparation of utilization in orbital missions.

KEY TDM PRECURSORS - TDM 2
ON-ORBIT SPACECRAFT ASSEMBLY TEST & LAUNCH

TECHNOLOGY DEVELOPMENT ELEMENT	(A) GROUND PRECURSOR	(B) STS PRECURSOR	STATUS
1. ORU REPLACEMENT IN EVA MODE	• UNDERWATER TEST	• DEMONSTRATION AND USE ON ORBITER MISSION(S)	(B) PROJECTED 1984 ON MMS
2. SPECIALIZED CREW SUPPORT EQUIPMENT DEVELOPMENT AND TEST	• UNDERWATER TESTS	• DEMONSTRATION AND USE ON ORBITER MISSION(S)	(B) START IN MID-'80s
3. DEMONSTRATION OF CHERRY PICKER IN SAT ASSEMBLY(1)	• SIMULATOR	• DEMONSTRATION AND USE ON ORBITER MISSION(S)	(B) PROJECTED START '84
4. DEMONSTRATION/USE OF HANDLING AIDS		• USE ON ORBITER MISSION(S)	(B) PROJECTED LATE '80s
5. FLUID TRANSFER		• TEST AND DEMONSTRATION ON PROTOTYPE UNIT	(B) 1984
		• USE ON SATELLITE REFUELING MISSION	(B) CONCEPT
6. UTILIZATION OF HUD IN EVA MODE(2)	• GROUND-BASED EVALUATIONS	• TEST AND UTILIZE HUD TECHNIQUES	CONCEPT
7. FULL-SCALE ASSEMBLY/TEST AND LAUNCH OF STS-DEPLOYED SATELLITE		• UTILIZATION ON ORBITER MISSIONS (INCLUDING RMS DEPLOYMENT AND SEPARATION OF SATELLITE)	CONCEPT

(1) SEE ALSO TDM-1, NO. 2

(2) SEE ALSO TDM-1, NO. 5

TDM 2 MISSION INTERFACES AND SUPPORT REQUIREMENTS

Unlike TDM 1, this mission comprises a mission peculiar space station interface, which is the command and telemetry link from the spacecraft to the space station. This interface is realized by the test/communications equipment listed under support equipment.

See Appendices B and C for additional detailing of space station requirements for support of this TDM.

TDM 2 MISSION INTERFACES AND SUPPORT REQUIREMENTS

TRW

	SPACE STATION	OTHER (NON SS)	MISSION PECULIAR	ASSUMED GENERIC
OPERATIONAL INTERFACE:				
SHUTTLE DOCKING AND CARGO TRANSFER	●			●
VIDEO AND VOICE COMMUNICATION WITH GROUND FACILITIES	●			●
RECEIVE TELEMETRY FROM AND ISSUE COMMANDS TO MODULAR SPACECRAFT	●		●	
PHYSICAL INTERFACE:				
SHUTTLE/SPACE STATION DOCKING FACILITY	●			●
CARGO TRANSFER FACILITIES	●			●
COMMUNICATIONS LINKS TO GROUND FACILITIES	●			●
COMMAND/TELEMETRY LINK FROM SPACE STATION TO MODULAR SPACECRAFT	●		●	
SUPPORT SERVICES:				
DESIGN AND MANUFACTURE MODULAR SPACECRAFT AND SUPPORT EQUIPMENT		●	●	
CREATE DETAILED PROCEDURES FOR ON-ORBIT CONSTRUCTION OPERATIONS		●	●	
MONITOR ON-ORBIT OPERATIONS AND RESOLVE ANOMALIES		●		●
SUPPORT EQUIPMENT:				
SPECIAL PACKING CONTAINERS		●	●	
SPECIAL ASSEMBLY TOOLS	●		●	
SPACECRAFT TEST/COMMUNICATIONS EQUIPMENT FOR SPACE STATION	●		●	
MISSION PECULIAR GROUND FACILITY SOFTWARE AND PROCEDURES		●	●	
SPACECRAFT MISSION TARGETING COMPUTER FOR SPACE STATION	●		●	

KEY BENEFITS OF TDM 2 ON-ORBIT SPACECRAFT, ASSEMBLY, TEST AND LAUNCH

The overall benefit of this TDM is to establish the space station as operational base beyond the Shuttle orbiter for assembling and deploying satellites. This permits launching satellites too large for being taken into orbit by the shuttle in one piece, and permits complex assembly/test operations too lengthy for a single shuttle sortie. Also, serving as a depot the space station stores materials, propellants or other liquids, and tools needed for on-orbit satellite assembly.

The chart lists seven TD elements and their individual benefits contributing to the above overall goals. Of particular interest are those TD elements (1 through 5) that directly serve to enhance crew capability, efficiency and productivity. As such they overlap with the TD element benefits provided by and previously discussed under TDM 1.

An important development in this context is the introduction and exploitation of heads-up display (HUD) techniques which are receiving increasing emphasis both by NASA and the USAF. These techniques put at the disposal of an EVA crew man the large data base and servicing instructions that are stored in the SS computer or are available from ground-based data sources, through uplink channels. As a result a major saving in time, cost and energy is achievable, human errors are avoided, and crew hazards are reduced.

KEY BENEFITS OF TDM 2
ON-ORBIT SPACECRAFT ASSEMBLY, TEST AND LAUNCH

TECHNOLOGY DEVELOPMENT ELEMENT	MISSION BENEFIT(S)
1. ORU REPLACEMENT IN EVA MODE	• ESSENTIAL ELEMENT IN ASSEMBLY, SERVICING AND REPAIR OF SATELLITES BY CREW
2. SPECIALIZED CREW SUPPORT EQUIPMENT DEVELOPMENT	• ENHANCES CREW EFFECTIVENESS AND SAFETY
3. USE OF CHERRY PICKER	• SAME AS TDM-1, NO. 2
4. USE OF HOLDING FIXTURE	• INCREASED P/L HANDLING FLEXIBILITY AND CONTROL
5. FLUID TRANSFER	• ESSENTIAL TO MOST SATELLITE SERVICING MISSIONS, INCLUDING PROPELLANT AND COOLANT TRANSFER OR RELOADING
6. HUD UTILIZATION IN EVA	• SAME AS TDM-1, NO. 5
7. PRIOR DEMONSTRATION OF OF SATELLITE ASSEMBLY TEST AND LAUNCH ON STS	• USHERS IN ERA OF SATELLITE ON-ORBIT ASSEMBLY • INCREASES EFFICIENCY OF LARGER SCALE ASSEMBLY ON SS

OVERALL TDM BENEFIT – ESTABLISHES SS AS OPERATIONAL BASE BEYOND STS FOR DEPLOYING LARGE SATELLITES

TASK 2.2 AND TASK 2.3

- SUBTASKS AND SUBTASK TOPICS COVERED FOR EACH TDM

  TASK 2.2 TDM OPERATIONS ANALYSIS
  - -- END-TO-END EVENT DEFINITION
  - -- TIMELINES (PRELIMINARY)
  - -- SUPPORT SERVICES NEEDED

  TASK 2.3 EARLY SPACE STATION ACCOMMODATION
  - -- INTERFACES
  - -- SUPPORT EQUIPMENT

- TDM ADDRESSED ON THE FOLLOWING PAGES

  TDM 1 BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY

  TDM 2 ON-ORBIT SPACECRAFT ASSEMBLY, TEST AND LAUNCH

  TDM 3 LARGE ANTENNA STRUCTURE DEPLOYMENT

  TDM 4 SERVICE/REFURBISH SATELLITE (GRO)

  TDM 5 SERVICING OF FREE-FLYING MATERIALS PROCESSING PLATFORM

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SATELLITE SERVICING - TDM 3 SUMMARY LARGE ANTENNA STRUCTURE DEPLOYMENT

Construction of large antennas in orbit involves problems in achieving precise geometries of large structures and in measuring and adjusting the antenna pattern. Far field measurements may require the test receiver to be many miles from the antenna. Because of the deforming effects of gravity, final antenna geometry adjustments are best done on orbit. This TDM is designed to develop the technologies required for these types of operations.

This mission features an antenna core structure designed to isolate the antenna dish structure from space station disturbance torques, a self-deploying antenna dish, and increased structural stiffness from members added via EVA after dish deployment.

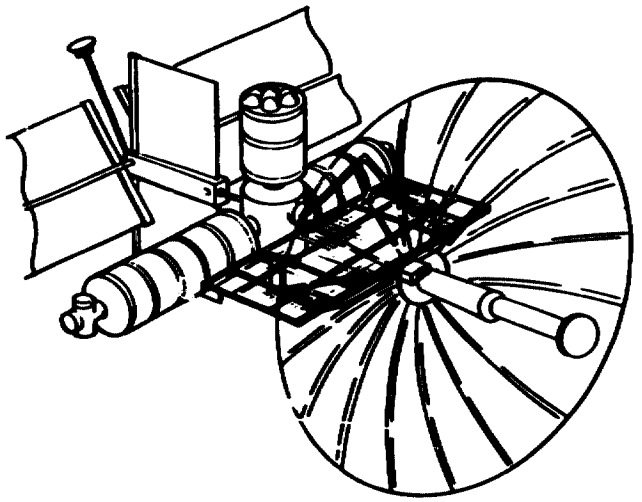
SATELLITE SERVICING - TDM #3 SUMMARY
LARGE ANTENNA STRUCTURE DEPLOYMENT

TRW

1. TECHNOLOGY DEVELOPMENT AREAS
   - EVA CONSTRUCTION
   - TMS OPERATIONS
   - AUTOMATED ANTENNA SHAPE CONTROL
   - MEASUREMENT & TEST OF LARGE STRUCTURE DYNAMICS
   - ON-ORBIT SYSTEM/SUBSYSTEM TEST
   - REMOTE RF MEASUREMENTS

2. BENEFITS
   - ANTENNAS MAY EXCEED SIZE AND WEIGHT LIMITATIONS OF SHUTTLE
   - PRECISE GEOMETRIES MAY BE ACHIEVED

3. SPACE STATION REQUIREMENTS SUMMARY
   - SPECIALIZED MECHANICAL AND CREW SUPPORT EQUIPMENT
   - OPTICAL/LASER SHAPE MONITORING
   - SHAPE CONTROL TECHNIQUES
   - PRECISION TRACKING AND CONTROL OF FREE FLYING (TMS) RECEIVER LOCATION
   - SPECIALIZED CREW TRAINING
   - AUTONOMOUS MISSION SUPPORT SYSTEMS



4. SCENARIO HIGHLIGHTS
   - SHUTTLE DELIVERS FOLDED ANTENNA STRUCTURE
   - CREW ERECTS ANTENNA DISH, AIDED BY LASER OR PASSIVE OPTICAL MEASUREMENTS
   - FREE FLYING PROBE (TMS) MEASURES ANTENNA PATTERN
   - ANTENNA TRIMMING AS REQUIRED

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TDM 3

MISSION SEQUENCE

LARGE ANTENNA STRUCTURE DEPLOYMENT

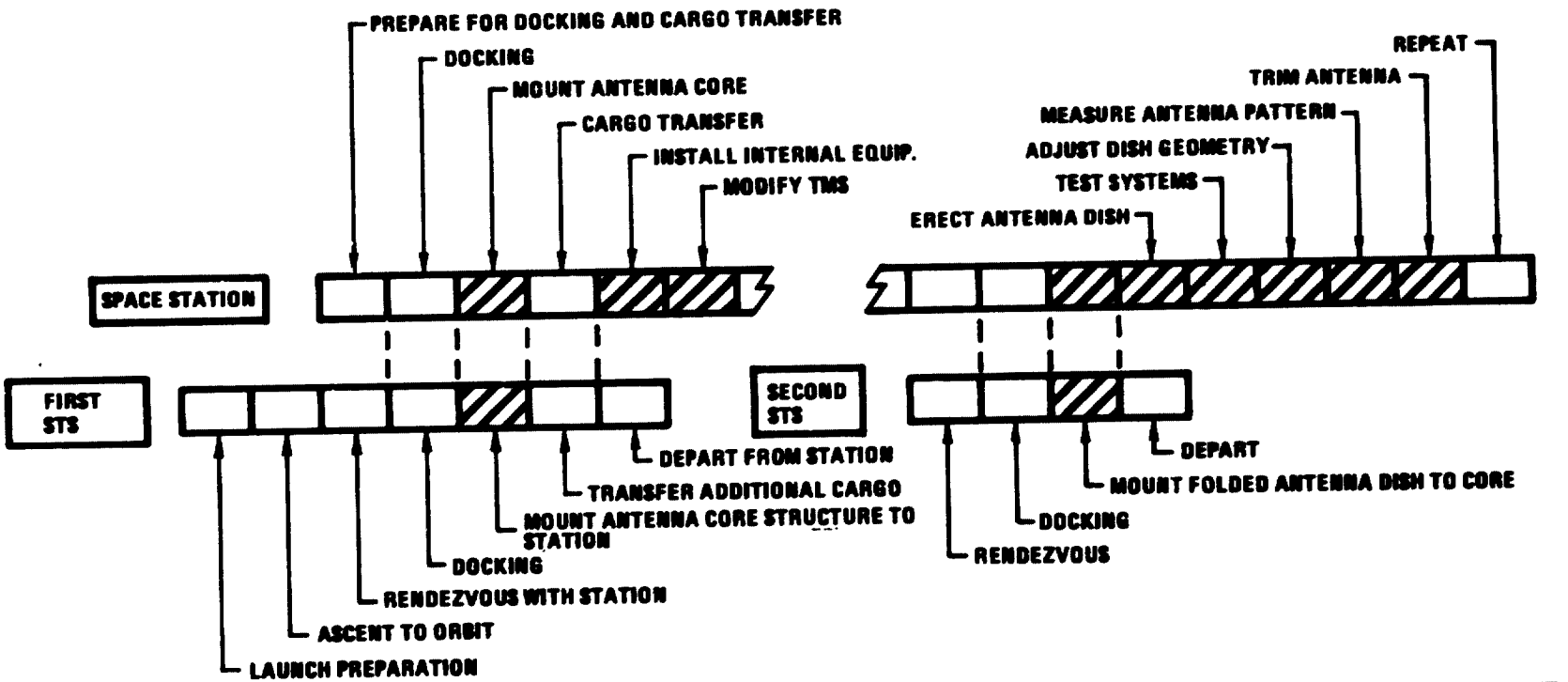
This TDM is divided into two major phases, keyed to two shuttle missions. The first shuttle delivers the antenna core structure and the equipment which must be installed in the space station and in the TMS to support this TDM.

When this installation has been completed by the space station astronauts, a second shuttle delivers the folded antenna structure and assists in mounting it to the core structure.

The remainder of the mission is conducted autonomously by the space station. When the mission is completed, the calibrated, 60 meter antenna is available for installation on its intended platform, however, this final installation is not part of this TDM.

Crosshatched events are those unique to this TDM and are detailed in subsequent charts.

TDM 3 MISSION SEQUENCE LARGE ANTENNA STRUCTURE DEPLOYMENT



- EXECUTIVE DIRECTION
- PROCEDURE MONITORING
- ANOMALY RESOLUTION

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The first three tasks detailed here are performed during and after the first STS delivery.

Mount Antenna Core

Because of the size of the total antenna structure, the core structure and dish structures are delivered on separate shuttle flights. After the first delivery, the core structure is unpacked and mounted on the service module air lock using the RMS.

Install Internal Equipment

Installation of the internal space station equipment needed for support of the erection, calibration, and testing of the large antenna is performed by the space station astronauts after shuttle departure. This may be a temporary installation, and the assumption is that the space station design accommodates this type of installation without requiring irreversible operations (cutting, drilling).

Modify TMS

Special equipment is installed in the TMS to support RF measurements to calibrate the large antenna. This is an EVA operation, and this scenario assumes that the TMS design is capable of supporting this type of temporary installation without requiring significant modification.

TDM-3 TASK DETAIL
MOUNT ANTENNA CORE
INSTALL INTERNAL EQUIPMENT
MODIFY TMS

TRW

MOUNT ANTENNA CORE

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
UNPACK CORE STRUCTURE	2					.5
TRANSFER CORE TO SERVICE MODULE AIR LOCK		YES				.3
SECURE WITH LATCHING MECHANISM	1	YES	YES			.3
ATTACH CABLES TO HULL FITTINGS	1		YES			.2
				TOTAL HOURS		1.3

INSTALL INTERNAL EQUIPMENT

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
UNPACK TEST SET, CABLES, FITTINGS	2					.5
MOVE INTO STATION THROUGH AIR LOCK	2	YES				1
ATTACH TEST SET TO EQUIPMENT RACK						.5
RUN CABLES TO CORE STRUCTURE						1
CHECKOUT INSTALLATION						1
				TOTAL HOURS		4

MODIFY TMS

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
UNPACK CALIBRATED ANTENNA	1		YES			.2
INSTALL ANTENNA ON TMS	1		YES			.3
UNPACK RF MEASURING UNIT/TRANSPONDER	1		YES			.2
INSTALL UNIT IN TMS	1		YES			.5
UNPACK CABLES AND FITTINGS	1		YES			.2
INSTALL IN TMS	1		YES			.5
CHECKOUT INSTALLATION	1		YES			.5
				TOTAL HOURS		2.4

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Mount Folded Antenna Dish to Core

This task is performed with the assistance of the RMA. Because the shuttle is docked to the space station at this time, the shuttle RMS can also assist in this operation.

The antenna dish structure is packed in the shuttle cargo bay in one piece, folded up to fit the sensors, motors and cables for the automatic erection system are already in place.

Erect Antenna Dish

After the folded dish structure has been mounted to the core and power and data connections made, the automatic erection process can be initiated.

For this study, a one-piece, automatically erecting antenna dish has been assumed. This approach requires a minimum of EVA labor. An alternative, more labor intensive approach requiring assembly of many parts by EVA astronauts should be critically compared with the automated approach in a further study.

TDM-3 TASK DETAIL
MOUNT FOLDED ANTENNA DISH TO CORE
ERECT ANTENNA DISH

MOUNT FOLDED ANTENNA DISH TO CORE

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
UNPACK ANTENNA DISH STRUCTURE	2		YES			.5
TRANSLATE TO CORE STRUCTURE		YES				.3
SECURE STRUCTURE WITH LATCHING MECHANISM	2	YES	YES			.3
CONNECT POWER AND DATA CABLES	2		YES			.3
CHECKOUT INSTALLATION	2		YES			.5
				TOTAL HOURS		1.9

ERECT ANTENNA DISH

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
APPLY POWER TO ERECTION SYSTEM						.1
MONITOR ERECTION PROCESS	2		YES			1
SECURE LATCHES WHEN ERECTION COMPLETE	2		YES			1
				TOTAL HOURS		2.1

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Test Systems

The dish geometry control system is an automated, interconnected system of sensors and actuators. The diagnostic testing program is computer controlled by a test/control set which was previously installed internally in the space station.

Adjust Dish Geometry

As mentioned previously, the dish geometry control system is a closed loop, computer controlled system. Its execution need only be monitored at the test/control set inside the space station.

TDM-3 TASK DETAIL
TEST SYSTEMS
ADJUST DISH GEOMETRY

TEST SYSTEMS

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
APPLY POWER TO DISH GEOMETRY CONTROL SYSTEM						.1
EXECUTE DIAGNOSTIC PROGRAM USING TEST/CONTROL SET						.3
				TOTAL HOURS		.4

ADJUST DISH GEOMETRY

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
ACTIVATE DISH GEOMETRY CONTROL SYSTEM USING TEST/CONTROL SET						.3
MONITOR GEOMETRY ADJUSTMENT PROGRAM EXECUTION						1
				TOTAL HOURS		1.3

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Measure Antenna Pattern

It has been assumed that the far field antenna pattern needs to be measured. If the beginning of the far field is defined as $2D^2/\lambda$, for a 60 meter antenna at λ=0.1 meters the far field begins at 72 KM.

In order to achieve this measurement sensor distance, a TMS mission is required.

Trim Antenna

When the antenna pattern has been measured and analyzed, it may be necessary to trim the dish geometry. In order to minimize iterations of trimming and remeasurement, the antenna trimming is also computer controlled.

TDM-3 TASK DETAIL
MEASURE ANTENNA PATTERN
TRIM ANTENNA

MEASURE ANTENNA PATTERN

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
READY TMS FOR MISSION						2
TARGET TMS AV'S						.5
TMS DEPARTS SPACE STATION						1
TMS NAVIGATES TO MEASUREMENT LOCATION						1
TMS EXECUTES MEASUREMENT PROGRAM						2
TMS RETURNS TO SPACE STATION						1
TMS DOCKS AND IS SECURED						1
				TOTAL HOURS		8.5

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TRIM ANTENNA

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
ANALYZE MEASURED ANTENNA PATTERN						2
EXECUTE DISH TRIM PROGRAM USING TEST/CONTROL SET						.3
REPEAT ANTENNA PATTERN MEASUREMENT IF NECESSARY						
				TOTAL HOURS		2.3

KEY TDM PRECURSORS - TDM 3 LARGE ANTENNA STRUCTURE DEPLOYMENT

The five TD elements listed in this chart concern the deployment of a large antenna dish, its shape measurement and control (by distributed actuators), measurement of the antenna beam pattern and demonstration of the antenna in mission related tasks. All of these TD elements except the fourth (antenna beam steering) are suitable for precursor demonstrations on the ground and on the shuttle orbiter. The most important (last) entry in this chart involves antenna performance verification in a mission related task, such as wide-band communication to a distant probe or subsatellite. Structural deformations due to pointing dynamics and thermal stress (transients after entering and leaving sun occultation by earth) are principal matters of concern that will be significant primarily for the proposed large antenna diameter (60 m).

A ground-based series of antenna shape measurements and control demonstrations were performed by NASA/LaRC with subsequent test series in progress at Harris Aerospace Company.

KEY TDM PRECURSORS - TDM 3
LARGE ANTENNA STRUCTURE DEPLOYMENT

TECHNOLOGY DEVELOPMENT ELEMENT	(A) GROUND PRECURSOR	(B) STS PRECURSOR	STATUS
1. ON-ORBIT DEPLOYMENT/ ERECTION OF LARGE ANTENNA STRUCTURE (AUTOMATIC/EVA ASSISTED)	• DEMONSTRATE WITH STRUCTURAL MODEL ON TEST STAND (SMALLER ANTENNA SIZE)	• SEVERAL ANTENNA DEPLOYMENT DEMONSTRATIONS ON ORBITER (UP TO 20M DIAMETER)	(A) MID-80s (B) LATE 80s
2. DEMONSTRATE/VERIFY ON-ORBIT LARGE ANTENNA SHAPE MEASUREMENT AND CONTROL TECHNIQUES	• GROUND DEMONSTRATIONS PERFORMED ON SMALLER ANTENNAS AT LaRC (1981)	• DEMONSTRATIONS ON-BOARD SHUTTLE ORBITER (SMALLER ANTENNA SIZE)	(B) MID-1980s
3. MEASURE ANTENNA BEAM PATTERN BY FREE FLYING PROBE	• CONVENTIONALLY PERFORMED ON SMALLER ANTENNAS (ANTENNA TEST FACILITY)	• PRECISION TRACKING AND POSITION CONTROL OF FREE-FLYING PROBE (e.g., MANEUVERING CAMERA UNIT	(B) PROJECTED MID-80s
4. DEMONSTRATE ANTENNA BEAM STEERING	–	–	
5. DEMONSTRATE/VERIFY ANTENNA PERFORMANCE IN MISSION RELATED TASKS	• DEMONSTRATE ON LARGE GROUND ANTENNAS	• DEMONSTRATE ON SMALLER ANTENNAS DEPLOYED FROM ORBITER	(B) MID-80s

This TDM is relatively ambitious and will require considerable support including development of peculiar test equipment and extensive plans and procedures.

Appendices B and C provide additional detail requirements imposed on the space station by this TDM.

TDM 3 MISSION INTERFACES AND SUPPORT REQUIREMENTS

TRW

	SPACE STATION	OTHER (NON SS)	MISSION PECULIAR	ASSUMED GENERIC
OPERATIONAL INTERFACES:				
SHUTTLE DOCKING AND CARGO TRANSFER	●			●
VIDEO AND VOICE COMMUNICATION WITH GROUND FACILITIES	●			●
RECEIVE TELEMETRY FROM AND ISSUE COMMANDS TO TMS	●			●
PHYSICAL INTERFACE:				
SHUTTLE/SPACE STATION DOCKING FACILITY	●			●
CARGO TRANSFER FACILITIES	●			●
COMMUNICATIONS LINKS TO GROUND FACILITIES	●			●
COMMAND/TELEMETRY LINK FROM SPACE STATION TO TMS	●			●
SUPPORT SERVICES:				
DESIGN AND MANUFACTURE ANTENNA STRUCTURE AND SUPPORT EQUIPMENT		●	●	
CREATE DETAILED PROCEDURES FOR ON-ORBIT CONSTRUCTION OPERATIONS		●	●	
MONITOR ON-ORBIT OPERATIONS AND RESOLVE ANOMALIES		●		●
CREATE DETAILED PROCEDURES FOR ANTENNA CALIBRATION AND MEASUREMENT		●	●	
SUPPORT EQUIPMENT:				
SPECIAL PACKING CONTAINERS		●	●	
SPECIAL ASSEMBLY TOOLS	●		●	
FIELD STRENGTH TEST SET FOR TMS	●		●	
MISSION PECULIAR GROUND FACILITY SOFTWARE AND PROCEDURES		●	●	
TRANSMITTER FOR ANTENNA FIELD OPERATIONS		●	●	

KEY BENEFITS OF TDM 3 LARGE ANTENNA STRUCTURE DEPLOYMENT

The overall benefit of this TDM is the establishment of the new technology of deploying/erecting large structures that require high precision in structural shape such as antennas in excess of 20 m diameter. Also it directly serves several new and ambitious space mission categories that depend critically on the availability of large antenna reflectors (e.g., radio astronomy, microwave radiometry, space-based radar and mobile unit satellite communication by spot beams) Problems to be resolved are the achievement of an accurate antenna shape, within specifications, by measurement of geometrical characteristics and adjusting/controlling the shape based on the detected local errors. Provision of structural damping often will be an important factor.

The four TD elements listed in this chart include the structural deployment, shape measurement and control by local sensors and a free-flying, antenna pattern scanning receiver unit, and demonstration/verification of antenna performance in specific mission-related modes. These TD elements have precursors on the shuttle orbiter, but in principle they do require the working space, tools and resources available only on the manned space station, and the extra time that can be utilized by the crew to complete their tasks (as opposed to the limited maximum shuttle stay time on orbit).

KEY BENEFITS OF TDM 3
LARGE ANTENNA STRUCTURE DEPLOYMENT

TECHNOLOGY DEVELOPMENT ELEMENT	MISSION BENEFIT(S)
1. DEMONSTRATE ON-ORBIT DEPLOYMENT/ERECTION OF LARGE ANTENNA STRUCTURE (AUTOMATIC/EVA ASSISTED)	• ENABLES CONSTRUCTION OF LARGE ANTENNAS FOR RADIO ASTRONOMY, MICROWAVE RADIOMETRY, SPACE-BASED LASER, MOBILE SATELLITE COMM • DEMONSTRATES AUTOMATIC AND MANUALLY ASSISTED ANTENNA DEPLOYMENT TECHNIQUES
2. DEMONSTRATE/VERIFY ON-ORBIT LARGE ANTENNA SHAPE MEASUREMENT AND CONTROL TECHNIQUES	• VERIFIES ACHIEVEMENT OF SPECIFIED ANTENNA SHAPE
3. MEASURE ANTENNA BEAM PATTERN BY FREE-FLYING PROBE (e.g., TMS)	• VERIFIES ANTENNA PATTERN IN NEAR OR FAR FIELD • ESTABLISHES/VERIFIES PRECISION CONTROL OF FREE FLYING PROBES
4. DEMONSTRATE/VERIFY ANTENNA PERFORMANCE IN MISSION-RELATED TASKS, e.g. RADIO ASTRONOMY, SPOT BEAM COMMUNICATION, MICROWAVE RADIOMETRY	• VERIFIES OVERALL ANTENNA PERFORMANCE IN OPERATING MODES DICTATED BY MISSION PROFILE (SEE ITEM 1)

OVERALL TDM BENEFIT – DEMONSTRATES AND VERIFIES ON-ORBIT CONSTRUCTION, MEASUREMENT AND CONTROL OF LARGE ANTENNAS NEEDED IN RADIO ASTRONOMY, MICROWAVE RADIOMETRY (GROUND OBSERVATION), SPACE-BASED RADAR, MOBILE COMM SATELLITE MISSIONS

TASK 2.2 AND TASK 2.3

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- SUBTASKS AND SUBTASK TOPICS COVERED FOR EACH TDM

  TASK 2.2 TDM OPERATIONS ANALYSIS
  - -- END-TO-END EVENT DEFINITION
  - -- TIMELINES (PRELIMINARY)
  - -- SUPPORT SERVICES NEEDED

  TASK 2.3 EARLY SPACE STATION ACCOMMODATION
  - -- INTERFACES
  - -- SUPPORT EQUIPMENT

- TDM ADDRESSED ON THE FOLLOWING PAGES

  TDM 1 BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY

  TDM 2 ON-ORBIT SPACECRAFT ASSEMBLY, TEST AND LAUNCH

  TDM 3 LARGE ANTENNA STRUCTURE DEPLOYMENT

  TDM 4 SERVICE/REFURBISH SATELLITE (GRO)

  TDM 5 SERVICING OF FREE-FLYING MATERIALS PROCESSING PLATFORM

SATELLITE SERVICING - TDM 4 SUMMARY - SERVICE/REFURBISH SATELLITE (GRO)(1)

This mission makes use of an existing satellite at its planned end of life. Because mission time constraints are not significant compared to a shuttle mission, even units not designed for on-orbit repair may be serviceable.

This mission may be thought of as a generic on-orbit satellite refurbishment mission for the space station.

(1) GRO - Gamma Ray Observatory

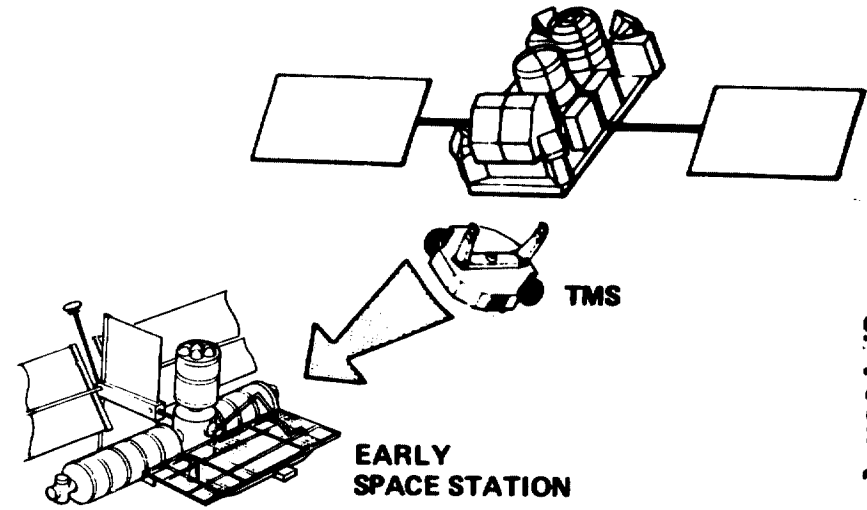
SATELLITE SERVICING - TDM #4 SUMMARY
SERVICE/REFURBISH SATELLITE (GRO)

TRW

1. TECHNOLOGY DEVELOPMENT AREAS
   - EVA CONSTRUCTION/DISASSEMBLY
   - ON ORBIT FLUID TRANSFER/STORAGE
   - TMS OPERATIONS
   - PART REPLACEMENT
   - CONTINGENCY SERVICE OPERATIONS
   - ON ORBIT SYSTEM/SUBSYSTEM TEST
   - SATELLITE RETRIEVAL
   - ADVANCED CREW SUPPORT TECHNOLOGIES

2. BENEFITS
   - EXTENSION OF LIFE OF GRO
   - APPLICABLE TO REPAIR/REFURBISHMENT OF MANY OTHER S/C

3. SPACE STATION REQUIREMENTS
   - MECH AND ELECT SUPPORT EQUIPMENT
   - CREW SUPPORT EQUIPMENT
   - REFILLABLE PROPELLANT TANKS
   - SPECIAL CREW TRAINING
   - AUTONOMOUS MISSION SUPPORT SYSTEMS



4. SCENARIO HIGHLIGHTS
   - GRO RETRIEVED FROM 400 KM ORBIT
   - COMPREHENSIVE STATUS TESTS
   - REFURBISHMENT/REPAIR OF UNITS
   - PROPELLANT REFILL
   - COMPREHENSIVE CHECKOUT
   - REDEPLOYMENT INTO OPERATIONAL ORBIT

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TDM 4

MISSION SEQUENCE

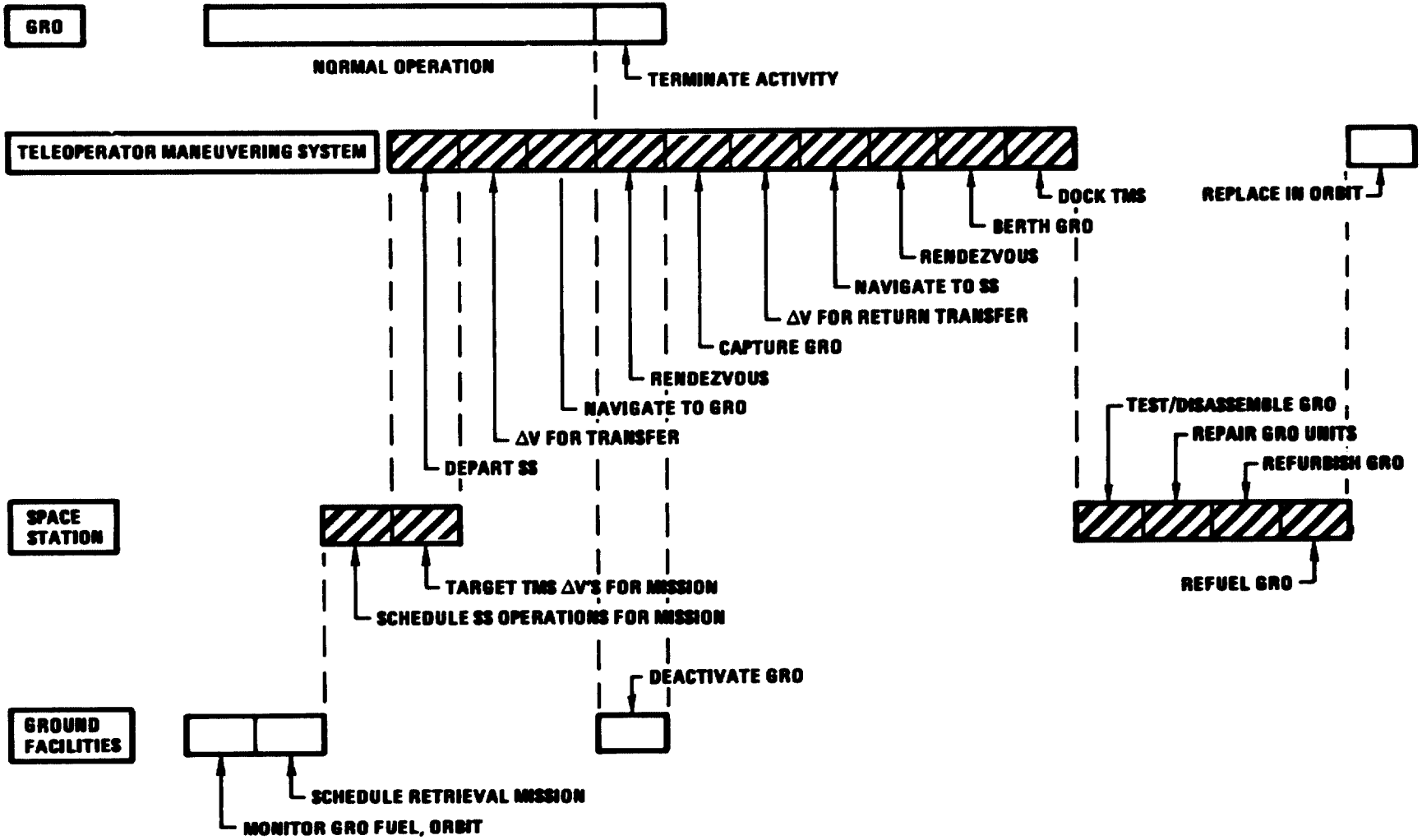
SERVICE/REFURBISH SATELLITE (GRO)

The Gamma Ray Observatory, which is in about the same orbit as the space station, is retrieved by the TMS. Once secured to the station, the GRO can be inspected, tested, disassembled and repaired. The space station can wait for delivery of parts or modules which are determined to need replacement.

Having been repaired, refurbished and refueled, the GRO may be replaced in orbit by the TMS for an extension of its planned mission.

The crosshatched events are unique to this TDM and are further detailed in subsequent charts.

TDM 4 MISSION SEQUENCE
SERVICE/REFURBISH SATELLITE (GRO)



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The GRO is controlled from ground facilities at Goddard Space Flight Center (GSFC). GRO retrieval mission planning would need to be coordinated between GSFC and the ground facility for the space station.

When the top level mission planning has been completed, the detailed scheduling of the operation is performed on board the space station, according to the assumption of desired space station autonomy.

TDM-4 TASK DETAIL
SCHEDULE OPERATIONS

TRW

TASK	GROUND FACILITIES	SPACE STATION
MONITOR GRO FUEL, ORBIT	ORBIT DETERMINATION AND MISSION PLANNING FUNCTIONS PREDICT GRO END OF LIFE.	
SCHEDULE RETRIEVAL MISSION	MISSION PLANNING FUNCTIONS CO-ORDINATE GRO AND SPACE STATION SCHEDULES.	
SCHEDULE SPACE STATION OPERATIONS FOR MISSION		SCHEDULING SOFTWARE SCHEDULES TMS OPERATION. CREW REVIEWS SCHEDULE, MODIFIES CONSTRAINTS AS REQUIRED, INITIATES SOFTWARE RESCHEDULING.

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TDM 4 TASK DETAIL

DISPATCH TMS

The TMS is assumed to have its own autonomous guidance and navigation subsystem. Targeting for the mission is done using a dedicated targeting computer on board the space station.

TDM-4 TASK DETAIL
DISPATCH TMS

TASK	SPACE STATION COMPUTER	SPACE STATION CREW	TELEOPERATOR MANEUVERING SYS.
TARGET TMS ΔV'S FOR MISSION	TARGETING SOFTWARE DETERMINES REQUIRED ΔV'S FOR TMS ORBIT TRANSFER TO GRO. COMMAND SOFTWARE TRANSMITS TARGETING DATA TO TMS GUIDANCE AND NAVIGATION SYSTEM.	CREW READIES TMS FOR GRO OPERATION.	POWER ON.
TMS DEPARTS SS		RELEASE TMS; COMMAND DEPARTURES FROM SS; ENABLES ΔV.	LOW THRUST DEPARTURE UNDER SS CREW CONTROL.
TRANSFER ORBIT INJECTION	MONITOR TMS TELEMETRY	MONITOR STATUS DISPLAYS.	EXECUTIVE AUTONOMOUS ΔV MANEUVER.
NAVIGATE TO GRO	MONITOR TMS TELEMETRY	MONITOR STATUS DISPLAYS.	AUTONOMOUS NAVIGATION.

TDM 4 TASK DETAIL

RETRIEVE GRO

The retrieval of the GRO requires coordinated activity on board the space station and at the GRO ground facilities. After the GRO is deactivated by ground command, the TMS capture of GRO is remotely controlled from the space station. The return trajectory is determined by TMS autonomous guidance, and docking is controlled by the space station.

TDM-4 TASK DETAIL
RETRIEVE GRO

TASK	GROUND FACILITIES	SPACE STATION	TELEOPERATOR MANEUVERING SYS.
RENDEZVOUS WITH GRO	COMMAND DEACTIVATION OF GRO.	MONITOR TMS TELEMETRY.	EXECUTE AUTONOMOUS ΔV MANEUVER.
CAPTURE GRO		CONTROL TMS CAPTURE OF GRO.	CAPTURE GRO WITH DEBRIS CAPTURE DEVICE.
ΔV FOR RETURN TRANSFER		ENABLE ΔV	EXECUTE AUTONOMOUS ΔV MANEUVER.
NAVIGATE TO SS		MONITOR TMS TELEMETRY.	AUTONOMOUS NAVIGATION.
RENDEZVOUS WITH SS		MONITOR TMS TELEMETRY.	EXECUTE AUTONOMOUS ΔV MANEUVER.
STOW GRO		TRANSFER GRO TO SS DECK AREA USING TMS.	APPROACH SS TMS.
DOCK TMS		CONTROL TMS/SS DOCKING.	EXECUTE DOCKING POWER OFF.

Test/Disassemble GRO

When the deactivated GRO is secured to the space station, servicing can commence with diagnostic testing. Examples of the kind of servicing that the space station can provide have been chosen. The defective units mentioned are small enough to bring into the space station through the airlock.

Repair GRO Units

Disassembly, troubleshooting, and repair of units in a shirtsleeve environment can only be performed on orbit in a space station, due to the time involved.

This type of operation can result in cost savings by requiring only small parts to be orbited for repair, rather than complete units and assemblies suitable for EVA changeout.

TDM-4 TASK DETAIL
TEST/DISASSEMBLE GRO
REPAIR GRO UNITS

TEST/DISASSEMBLE GRO

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
CONNECT STATION POWER AND DATA LINES	1					.5
EXECUTE DIAGNOSTIC TESTS						3
DISCONNECT AND REMOVE ONE BATSE UNIT	1		YES			.5
BRING INTO STATION THROUGH AIR LOCK	1		YES			.5
DISCONNECT AND REMOVE COMPTEL ELECTRONICS PANEL	1		YES			.5
BRING INTO STATION THROUGH AIR LOCK	1		YES			.5
				TOTAL HOURS		5.5

REPAIR GRO UNITS

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
DISASSEMBLE BATSE UNIT						1
TROUBLESHOOT UNIT						5
REPAIR UNIT						1
REASSEMBLE UNIT						1
DISASSEMBLE COMPTEL UNIT						1
TROUBLESHOOT UNIT						5
REPAIR UNIT						1
REASSEMBLE UNIT						1
				TOTAL HOURS		16

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Refurbish GRO

After repair, the units are reassembled to the GRO. For this mission, it has been assumed that deterioration in solar panel function is to be corrected by the retrofitting of small auxiliary solar panels to restore full output.

The refurbishment is completed when all diagnostic tests have been successfully executed.

Refuel GRO

A simple scenario has been assumed for the refueling of GRO. Detailed studies of GRO on orbit refueling are currently being conducted under the GRO contract.

REFURBISH GRO

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
TRANSFER REPAIRED BATSE UNIT TO GRO THROUGH AIR LOCK	1		YES			.5
REINSTALL BATSE UNIT	1		YES			.5
EXECUTE DIAGNOSTIC TESTS						.2
TRANSFER REPAIRED COMPTEL UNIT TO GRO THROUGH AIR LOCK	1		YES			.5
REINSTALL COMPTEL UNIT	1		YES			.5
EXECUTE DIAGNOSTIC TESTS						.2
UNPACK 'PIGGYBACK' AUXILIARY SOLAR PANELS	1					.3
INSTALL AUXILIARY SOLAR PANELS TO GRO	2		YES			1
TEST SOLAR PANEL FUNCTION						.5
EXECUTE DIAGNOSTIC TESTS						3
				TOTAL HOURS		7.2

REFUEL GRO

TASK	EVA	RMS	CHERRY PICKER	MMU	TMS	TIME, HOURS
CONNECT SUPPLY HOSE TO GRO INTAKE VALVE	1					.5
BLEED GRO TANK RESIDUAL PRESSURE	1					.2
CLOSE BLEED VALVE	1					.1
OPEN SUPPLY VALVE	1					.1
MONITOR GRO TANK PRESSURE						.2
SHUTOFF SUPPLY VALVE WHEN DESIRED PRESSURE IS REACHED	1					.1
CLOSE GRO TANK INLET VALVE	1					.1
BLEED SUPPLY HOSE	1					.1
DISCONNECT SUPPLY HOSE FROM GRO AND STOW	1					.5
				TOTAL HOURS		1.9

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This chart presents data from the Vought study of TMS support to the GRO while based on the Space Station.

In this study, the GRO and space station were assumed to be in the same orbit at an altitude of 216 n.mi. In this scenario, the TMS must make altitude changes to rendezvous with the GRO and then with the space station. Mission time and TMS propellant usage for GRO retrieval were derived parametrically as functions of orbital separation and TMS altitude change.

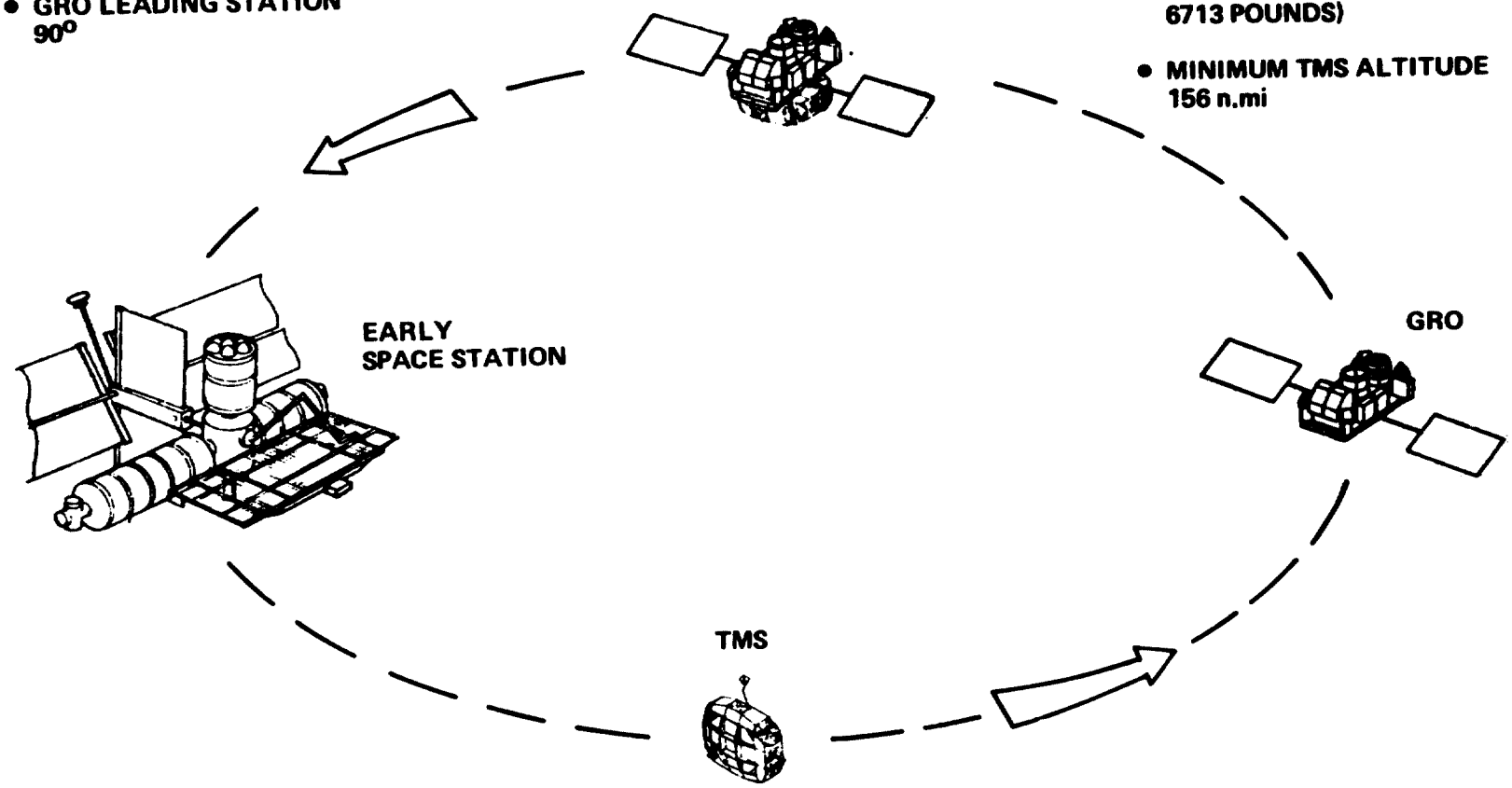
This chart shows data for a sample point in the parametric range of the study.

RETRIEVAL OF GRO (VOUGHT STUDY)

- STATION AND GRO ALTITUDE 216 n.mi
- GRO LEADING STATION 90°

SAMPLE POINT

- MISSION TIME 27.6 HOURS
- TMS PROPELLANT USED 2360 POUNDS (CAPACITY 6713 POUNDS)
- MINIMUM TMS ALTITUDE 156 n.mi



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KEY TDM PRECURSORS - TDM 4 SERVICE/REFURBISH SATELLITE (GRO)

Together with TDM 5 (Servicing of a Materials Processing Platform) this TDM will involve servicing operations most frequently required in the era of the manned space station. Ground-based tests and simulations will therefore be important precursors in the evolution of the servicing techniques required.

Shuttle-based precursor missions will be performed in the mid-80's in retrieving and servicing satellites such as the Solar Max spacecraft and GRO. The latter may also include fluid transfer in the orbiter payload bay. The MMS spacecraft, designed for serviceability on orbit (removable ORUs) will be a logical candidate for these precursor activities, and the results will provide an essential verification step preparatory to the more demanding repair/refurbishment tasks anticipated during satellite servicing on the space station.

KEY TDM PRECURSORS - TDM 4 SERVICE/REFURBISH SATELLITE (GRO)

TECHNOLOGY DEVELOPMENT ELEMENT	(A) GROUND PRECURSOR	(B) STS PRECURSOR	STATUS
1. TEST/DEMONSTRATION OF ORU REPLACEMENT IN EVA MODE(1)	• UNDER WATER TEST	• ON-ORBIT TEST AND UTILIZATION ON SOLAR-MAX MISSION	(B) PROJECTED FOR 1984
2. SATELLITE RETRIEVAL DEMONSTRATION BY CREW MAN USING MMU	• GROUND BASED SIMULATION AND TRAINING, INCLUDING UNDERWATER TESTS	• ON-ORBIT UTILIZATION ON SOLAR MAX MISSION	(B) PROJECTED FOR 1984
3. HUD UTILIZATION ON ORBITER-BASED SATELLITE REPAIR MISSIONS(2)	• GROUND-BASED EVALUATION SERIES	• ORBITER-BASED OPERATIONAL USE OF HUD	TBD
4. TMS USE IN SATELLITE RETRIEVAL AND REDEPLOYMENT	• GROUND-BASED SIMULATIONS BY TMS MODEL	• ORBITER-BASED OPERATIONAL USE OF TMS	(B) LATE 80s
5. FLUID TRANSFER(3)		• OPERATIONAL USE ON GRO REFUELING MISSION	(B) ~1989

(1)SEE ALSO TDM-2, NO. 1 (2)SEE ALSO TDM-1, NO. 5 (3)SEE ALSO TDM-2, NO. 5

The mission peculiar space station interfaces for this mission are the satellite berthing area, power and data lines, and fuel transfer facility. Since these facilities may be thought of as generic satellite servicing facilities for the space station, their cost should not be totally assigned to this mission.

The support services and equipment for this mission depend upon exactly what needs to be done to refurbish the GRO. An arbitrary set of operations has been assumed for costing purposes.

Additional more detail space station requirements imposed by this TDM are contained in Appendices B and C.

TDM 4 MISSION INTERFACES AND SUPPORT REQUIREMENTS

TRW

	SPACE STATION	OTHER (NON SS)	MISSION PECULIAR	ASSUMED GENERIC
OPERATIONAL INTERFACE:				
SHUTTLE DOCKING AND CARGO TRANSFER	●			●
VIDEO AND VOICE COMMUNICATION WITH GROUND FACILITIES	●			●
PHYSICAL INTERFACE:				
SHUTTLE/SPACE STATION DOCKING FACILITY	●			●
CARGO TRANSFER FACILITIES	●			●
COMMUNICATIONS LINKS TO GROUND FACILITIES	●			●
BERTHING AREA	●		●	
POWER AND DATA LINES	●			●
FUEL TRANSFER FACILITY	●			●
SUPPORT SERVICES:				
SUPPLY REQUIRED PARTS AND FUEL		●	●	
CREATE DETAILED PROCEDURES FOR ON-ORBIT SERVICING OPERATIONS		●	●	
MONITOR ON-ORBIT OPERATIONS AND RESOLVE ANOMALIES		●		●
SUPPORT EQUIPMENT:				
SPECIAL ASSEMBLY TOOLS	●		●	
SPECIAL TEST EQUIPMENT	●		●	

KEY BENEFITS OF TDM 4 SERVICE/REFURBISH SATELLITE (GRO)

The overall benefit of this TDM is to establish and demonstrate on-orbit procedures for extending the useful life of operational satellites; refurbishment and resupply of consumables; replacement of failed or worn-out parts; and changeout of payload elements, to serve the needs of a wider user community. These tasks constitute the majority of on-orbit servicing as commonly viewed by system planners and project management. This TDM therefore is one of the most important ones in the entire range of TDM candidates investigated. It also tends to be among the most complex and diversified technology developments.

The five TD elements identified in the chart emphasize crew procedures, crew support equipment, and crew utilization modes (e.g., heads-up display provisions) and overlap in part with TD elements called out in the preceding TDM's. A key benefit of establishing such procedures by TDM 4 is to gain increased confidence in planning for future use of on-orbit maintenance activities as a routine assignment to the SS crew. It thus provides a critical shake-down or "debugging" phase in the overall evolution of man-in-space technology and space station capability.

KEY BENEFITS OF TDM 4 SERVICE/REFURBISH SATELLITE (GRO)

TECHNOLOGY DEVELOPMENT ELEMENT	MISSION BENEFIT(S)
1. ORU REPLACEMENT IN EVA MODE	• SAME AS TDM-2, NO. 1
2. SATELLITE RETRIEVAL BY CREWMAN USING MMU	• EXTENDS SATELLITE RETRIEVAL CAPABILITY TO FAILED OR NON-COOPERATING SATELLITES (EXAMPLE = SOLAR MAX MISSION) • INCREASES SATELLITE SERVICING OPTIONS TO WIDER CLASS OF CANDIDATE SATELLITES, AND BACKS UP TMS MODE
3. HUD UTILIZATION	• SAME AS TDM-1, NO. 5 AND TDM-2, NO. 6
4. TMS USE IN SATELLITE RETRIEVAL AND REDEPLOYMENT	• PREREQUISITE TO PERFORMING ROUTINE RETRIEVAL/REDEPLOYMENT IN MOST SATELLITE MAINTENANCE/REPAIR/REFURBISHMENT MISSIONS, ESPECIALLY ON SATELLITES NOT CAPABLE OF PERFORMING REQUIRED MANEUVERING
5. FLUID TRANSFER	• SAME AS TDM-2, NO. 5

OVERALL TDM BENEFIT – EXTENDS LIFE OF SATELLITES, INCREASES UTILITY TO WIDER USER COMMUNITY, ACHIEVES LARGE COST SAVINGS

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TASK 2.2 AND TASK 2.3

- SUBTASKS AND SUBTASK TOPICS COVERED FOR EACH TDM

TASK 2.2 TDM OPERATIONS ANALYSIS	TASK 2.3 EARLY SPACE STATION ACCOMMODATION
-- END-TO-END EVENT DEFINITION	-- INTERFACES
-- TIMELINES (PRELIMINARY)	-- SUPPORT EQUIPMENT
-- SUPPORT SERVICES NEEDED	

- TDM ADDRESSED ON THE FOLLOWING PAGES

TDM 1 BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY

TDM 2 ON-ORBIT SPACECRAFT ASSEMBLY, TEST AND LAUNCH

TDM 3 LARGE ANTENNA STRUCTURE DEPLOYMENT

TDM 4 SERVICE/REFURBISH SATELLITE (GRO)

TDM 5 SERVICING OF FREE-FLYING MATERIALS PROCESSING PLATFORM

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SATELLITE SERVICING - TDM 5 SUMMARY SERVICING OF FREE-FLYING MATERIALS PROCESSING PLATFORM

This TDM differs from the first four in that it is an open ended, pilot plant operation which can develop into a continuous operational mission. Only one servicing cycle is considered here. They should be all alike, unless repairs to the MPP become necessary. In this event the MPP would be returned to the space station.

Mission & Systems Engineering
TRW Space & Technology Group

SATELLITE SERVICING - TDM #5 SUMMARY
SERVICING OF FREE-FLYING MATERIALS PROCESSING PLATFORM

TRW

1. TECHNOLOGY DEVELOPMENT AREAS

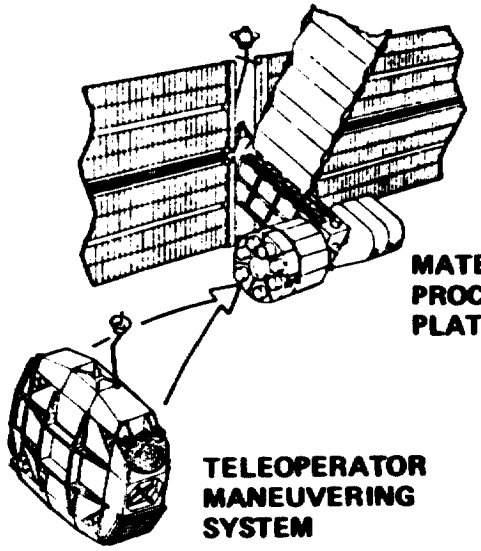
- ON ORBIT LOGISTICS CONTROL
- REMOTE RESUPPLY AND HARVESTING
- REMOTE REBOOST
- TMS OPERATIONS

2. BENEFITS

- ACHIEVE ROUTINE SUPPLY/HARVESTING, ESSENTIAL TO COMMERCIAL SPACE PROCESSING

3. SPACE STATION REQUIREMENTS

- TMS WITH SERVICE ATTACHMENT OPERATIONAL
- TV CONTROLLED REMOTE TMS OPERATIONS
- SPACE PROCESSING PLATFORM DESIGNED FOR REMOTE SERVICING
- RENDEZVOUS OPERATIONS SCHEDULE MONITORED AND CONTROLLED TO FACILITATE ROUTINE UNMANNED SERVICING SORTIES



4. SCENARIO HIGHLIGHTS

- TMS DOCKS AT PLATFORM
- TMS DELIVERS AND EXCHANGES SAMPLE MAGAZINES, RETURNS FINISHED SAMPLES TO SS
- IN-SITU TMS OPERATIONS CONTROLLED REMOTELY FROM SS VIA TV LINK
- TMS ALSO PERFORMS ORBIT REBOOST OF PLATFORM ON COMMAND FROM SS

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TDM 5

MISSION SEQUENCE

SERVICING OF FREE-FLYING MATERIALS PROCESSING PLATFORM

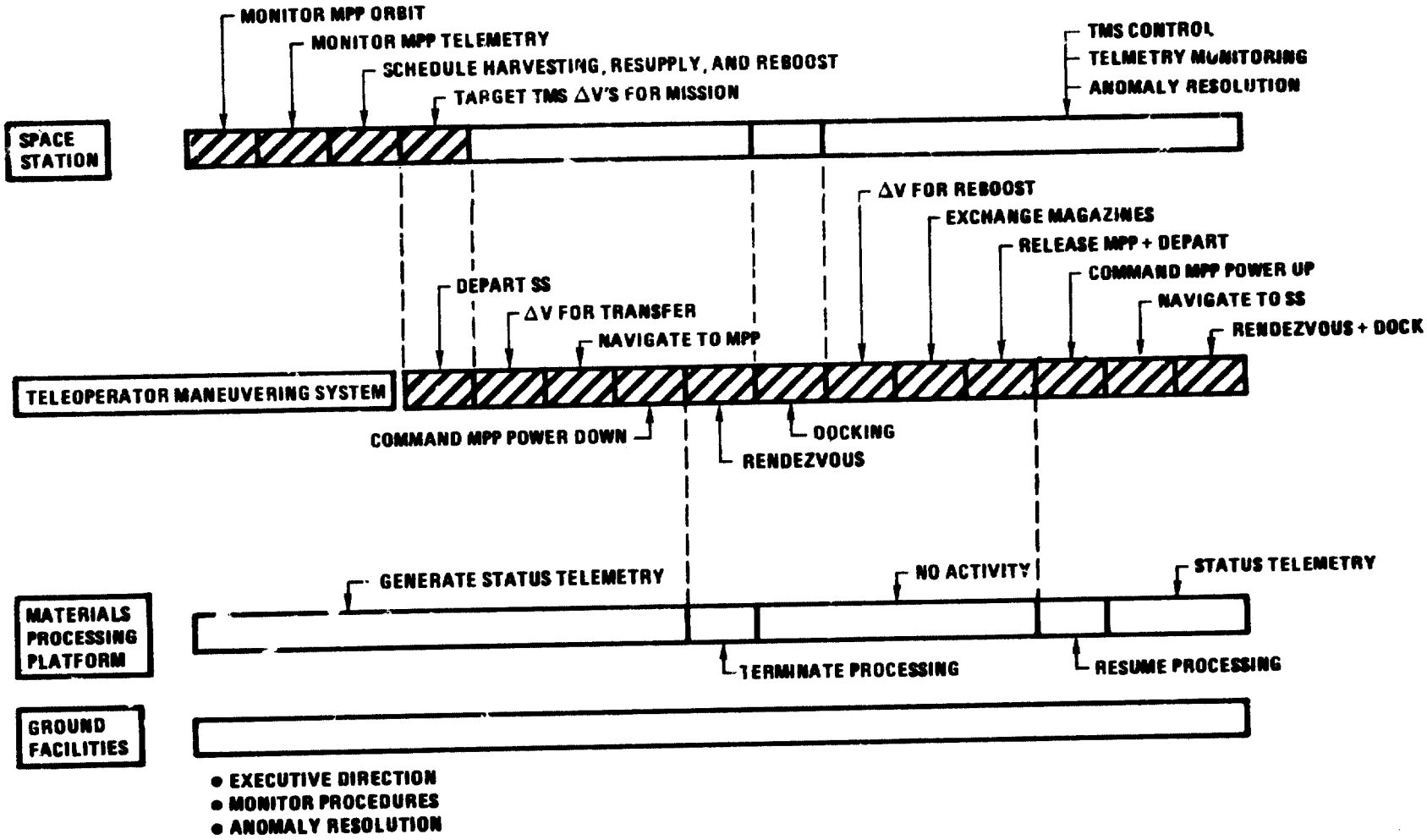
This sequence diagram involves activities of the space station, a materials processing platform nearby, and a teleoperator maneuvering system. The space station determines the need for and schedules the servicing mission. The free-flying platform has a largely passive role, generating telemetry except when shut down by command upon approach of the TMS.

The control of this mission is entirely by the space station. It monitors the platform telemetry and commands the TMS. Again the role of the ground facilities is limited except in the case of an anomaly.

TDM-unique events are crosshatched and further detailed in subsequent charts.

Mission & Systems Engineering
TRW Space & Technology Group

TDM 5 MISSION SEQUENCE SERVICING OF FREE-FLYING MATERIALS PROCESSING PLATFORM

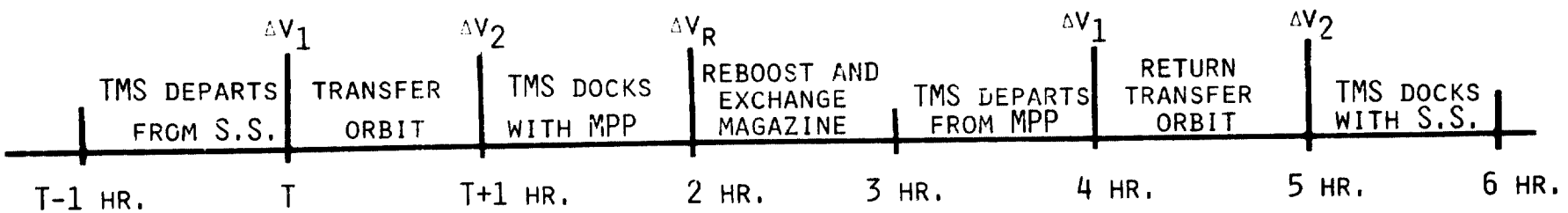


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TDM 5 MISSION TIMELINE

An approximate TMS mission timeline for servicing the MPP has been assumed. The total mission duration is approximately six hours for an MPP at a distance of 6 n.mi. A further study could accurately determine times and ΔV's by simulation.

TDM-5
MISSION TIMELINE



ASSUMED S.S. - MPP DISTANCE 6 N. MI

$\Delta V_N \simeq 10$ FPS

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TDM 5 TASK DETAIL
SCHEDULE OPERATIONS

In line with the concept of space station autonomy, the functions of monitoring the MPP and scheduling servicing missions is performed on board the space station. In order to perform these functions with a minimum of manpower, extensive software systems will be required. Much further study needs to be done on space station software and computer requirements to support desired space station autonomy.

TDM-5 TASK DETAIL
SCHEDULE OPERATIONS

TASK	TIME	SPACE STATION COMPUTER	SPACE STATION CREW
MONITOR MPP ORBIT	WEEKLY	ORBIT DETERMINATION SOFTWARE UPDATES MPP ORBIT PERIODICALLY, USING S.S. RADAR OBSERVATIONS. O.D. SOFTWARE PREDICTS TIME FOR REQUIRED MPP REBOOST AND OUTPUTS TIME TO SCHEDULING SOFTWARE.	
MONITOR MPP TELEMETRY	DAILY	TELEMETRY PROCESSING SOFTWARE MONITORS MPP TELEMETRY PERIODICALLY. T.P. SOFTWARE PREDICTS TIME FOR REQUIRED MPP HARVESTING AND RESUPPLY AND OUTPUTS TIME TO SCHEDULING SOFTWARE.	
SCHEDULING HARVESTING, RESUPPLY AND REBOOST	T-1 WEEK	SCHEDULING SOFTWARE SCHEDULES TMS OPERATION.	CREW REVIEWS SCHEDULE, MODIFIES CONSTRAINTS AS REQUIRED, INITIATES SOFTWARE RESCHEDULING.

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TDM 5 TASK DETAIL

DISPATCH TMS

This operation is identical to that previously described for the retrieval of the GRO in TDM 4.

TDM-5 TASK DETAIL
DISPATCH TMS

TASK	TIME	SPACE STATION COMPUTER	SPACE STATION CREW	TELEOPERATOR MANEUVERING SYS.
TARGET TMS ΔV'S FOR MISSION	T- 1 DAY	TARGETING SOFTWARE DETERMINES REQUIRED ΔV'S FOR TMS ORBIT TRANSFER TO MPP.	CREW READIES TMS FOR MPP OPERATION.	
	T- 1 HOUR	COMMAND SOFTWARE TRANSMITS TARGETING DATA TO TMS GUIDANCE AND NAVIGATION SYSTEM.		POWER ON.
TMS DEPARTS SS	T- ½ HOUR		RELEASE TMS; COMMAND DEPARTURE FROM SS; ENABLE ΔV.	LOW THRUST DEPARTURE UNDER SS CREW CONTROL.
TRANSFER ORBIT INJECTION	T	MONITOR TMS TELEMETRY	MONITOR STATUS DISPLAY.	EXECUTE AUTONOMOUS ΔV MANEUVER.
NAVIGATE TO MPP		MONITOR TMS TELEMETRY.	MONITOR STATUS DISPLAYS.	AUTONOMOUS NAVIGATION.

TDM 5 TASK DETAIL

SERVICE MPP

The navigation and rendezvous of the TMS with the MPP is autonomously controlled by the TMS guidance and navigation subsystem. The docking and servicing operations can be controlled from the space station in a stereo TV and other telemetry.

TDM-5 TASK DETAIL
SERVICE MPP

TASK	TIME	SPACE STATION COMPUTER	SPACE STATION CREW	TELEOPERATOR MANEUVERING SYS.
RENDEZVOUS WITH MPP	T+ 1 HOUR	MONITOR TMS TELEMETRY.	MONITOR STATUS DISPLAYS.	EXECUTE AUTONOMOUS ΔV MANEUVER.
DOCKING WITH MPP	T+ 2 HOURS		COMMAND MPP POWER DOWN CONTROL TMS/MPP DOCKING.	DOCK UNDER SS CREW CONTROL VIA TV.
REBOOST	T+ 2½ HRS.		ENABLE REBOOST MANEUVER.	EXECUTIVE AUTONOMOUS REBOOST MANEUVER.
EXCHANGE MAGAZINES	T+ 3 HRS.		COMMAND TMS EXCHANGE OF MPP PRODUCT AND SUPPLY MAGAZINES.	EXECUTE MAGAZINE EXCHANGE.
TMS DEPARTS MPP	T+ 4 HRS.	TARGETING SOFTWARE REDETERMINES TMS RETURN ORBIT ΔV'S USING CURRENT MPP ORBIT DATA.	COMMAND TMS/MPP UNDOCKING COMMAND MPP POWER UP ENABLE ΔV MANEUVER.	DEPART VICINITY OF MPP. EXECUTE AUTONOMOUS MANEUVER.

TDM 5 TASK DETAIL

TMS RETURN

The TMS return is again autonomously controlled by the TMS guidance and navigation subsystem. After docking of the TMS with the space station, EVA servicing of the TMS will be required.

TDM-5 TASK DETAIL
SERVICE MPP

TASK	TIME	SPACE STATION COMPUTER	SPACE STATION CREW	TELEOPERATOR MANEUVERING SYS.
RENDEZVOUS WITH MPP	T+ 1 HOUR	MONITOR TMS TELEMETRY.	MONITOR STATUS DISPLAYS.	EXECUTE AUTONOMOUS ΔV MANEUVER.
DOCKING WITH MPP	T+ 2 HOURS		COMMAND MPP POWER DOWN CONTROL TMS/MPP DOCKING.	DOCK UNDER SS CREW CONTROL VIA TV.
REBOOST	T+ 2½ HRS.		ENABLE REBOOST MANEUVER.	EXECUTIVE AUTONOMOUS REBOOST MANEUVER.
EXCHANGE MAGAZINES	T+ 3 HRS.		COMMAND TMS EXCHANGE OF MPP PRODUCT AND SUPPLY MAGAZINES.	EXECUTE MAGAZINE EXCHANGE.
TMS DEPARTS MPP	T+ 4 HRS.	TARGETING SOFTWARE REDETERMINES TMS RETURN ORBIT ΔV'S USING CURRENT MPP ORBIT DATA.	COMMAND TMS/MPP UNDOCKING COMMAND MPP POWER UP ENABLE ΔV MANEUVER.	DEPART VICINITY OF MPP. EXECUTE AUTONOMOUS MANEUVER.

TDM 5 TASK DETAIL

TMS RETURN

The TMS return is again autonomously controlled by the TMS guidance and navigation subsystem. After docking of the TMS with the space station, EVA servicing of the TMS will be required.

TDM-5 TASK DETAIL
TMS RETURN

TASK	TIME	SPACE STATION COMPUTER	SPACE STATION CREW	TELEOPERATOR MANEUVERING SYS.
NAVIGATE TO SS AND RENDEZVOUS	T+ 5 HRS.	MONITOR TMS TELEMETRY.	MONITOR STATUS DISPLAY.	AUTONOMOUS NAVIGATION. EXECUTE AUTONOMOUS ΔV MANEUVER.
DOCKING WITH S.S.	T+ 6 HRS.		CONTROL TMS/ S.S. DOCKING	EXECUTE DOCKING. POWER OFF.
			TRANSFER MAGAZINES TO CARGO AREA SERVICE TMS.	

KEY TDM PRECURSORS - TDM 5 SERVICING FREE-FLYING MATERIALS PROCESSING PLATFORM

The anticipated frequent requirement of servicing a free flying materials processing platform in the space station era, for purposes of resupply of new sample material and return of finished samples, demands a fully mature technology of routine, remotely controlled, in-situ operations. Ground-based demonstration and pathfinder tests with various types of materials processing facilities and subsequent on-orbit demonstrations on the shuttle are important stepping stones to developing this technology and gaining confidence in fault-free operational routines.

Although the actual remote servicing techniques will not likely be demonstrated prior to the advent of the space station, we anticipate that some TMS sorties from the shuttle will be flown in the late 1980's as precursor to the automated operations of in-situ module handling in the space station era. Further study will be required. The timely availability of TMS for early orbital application (prior to 1990) will be a prerequisite to achieving the TD element No. 3 listed in the chart. Also, this precursor depends on the state of development of materials processing platforms.

KEY TDM PRECURSORS - TDM 5
SERVICING MATERIALS PROCESSING PLATFORM

C-3

TECHNOLOGY DEVELOPMENT ELEMENT	(A) GROUND PRECURSOR	(B) STS PRECURSOR	STATUS
1. DEMONSTRATE CHANGE-OUT OF PROCESSING MODULES OR SAMPLE MAGAZINES a) IN HANDS-ON MODE b) IN HANDS-OFF MODE	• PATHFINDER DEMONSTRATIONS ON GROUND • UNDERWATER TESTS	• SHUTTLE-BASED MPS EXPERIMENT SERVICING a) EVA MODE b) RMS OPERATED	(B) LATE 80s
2. RETRIEVAL/REDEPLOYMENT OF FREE-FLYING PROCESSING PLATFORM (PP) FOR SERVICING ON-BOARD SS	(SEE TDM 4, NO. 4	(SEE TDM 4, NO. 4)	(B) LATE 80s
3. IN-SITU (OFF-BOARD) PP SERVICING BY TMS BY CHANGEOUT OF a) ENTIRE PROCESS MODULES b) SAMPLE MAGAZINES	• GROUND-BASED DEMONSTRATION AND PATHFINDER TESTS, BOTH (a) AND (b)	• SHUTTLE CONTROLLED IN-SITU PP SERVICING BY TMS (CONCEIVABLE, BUT NOT LIKELY TO BE PERFORMED, DEPENDING ON MPS PROGRAM EVOLUTION)	(B) TBD
		• AUTOMATED TMS RENDEZVOUS ON SHUTTLE IS A DESIRABLE PRECURSOR[1]	(B) TBD

[1]SEE ALSO TMS-4, NO. 4

TDM 5 MISSION INTERFACES AND SUPPORT REQUIREMENTS

The space station interfaces peculiar to this mission are largely communication interfaces. The physical interface is via the TMS.

This mission requires extensive specialized support equipment and services due to its automated, near-autonomous on-orbit operation.

Appendices B and C have additional detail about requirements of the space station for this TDM.

TDM 5 MISSION INTERFACES AND SUPPORT REQUIREMENTS

	SPACE STATION	OTHER (NON SS)	MISSION PECULIAR	ASSUMED GENERIC
OPERATIONAL INTERFACES:				
SHUTTLE DOCKING AND CARGO TRANSFER	●			●
VIDEO AND VOICE COMMUNICATION WITH GROUND FACILITIES	●			●
RECEIVE TELEMETRY FROM AND ISSUE COMMANDS TO MPP	●		●	
RECEIVE TELEMETRY FROM AND ISSUE COMMANDS TO TMS	●			●
PHYSICAL INTERFACE:				
SHUTTLE/SPACE STATION DOCKING FACILITY	●			●
CARGO TRANSFER FACILITIES	●			●
COMMUNICATIONS LINKS TO GROUND FACILITIES	●			●
COMMAND/TELEMETRY LINK FROM SPACE STATION TO MPP	●		●	
COMMAND/TELEMETRY LINK FROM SPACE STATION TO TMS	●			●
TMS/MPP MAGAZINE EXCHANGE SYSTEM	●		●	
SUPPORT SERVICES:				
DESIGN AND MANUFACTURE MPP AND SUPPORT EQUIPMENT		●	●	
CREATE DETAILED PROCEDURES FOR ON-ORBIT MPP SERVICING OPERATIONS		●	●	
MONITOR ON-ORBIT OPERATIONS AND RESOLVE ANOMALIES		●		●
GROUND FACILITIES PROVIDE RAW MATERIALS AND ACCEPT FINISHED PRODUCT		●	●	
SUPPORT EQUIPMENT:				
SPECIAL PACKING CONTAINERS		●	●	
SPECIAL ASSEMBLY TOOLS	●		●	
MPP MONITORING SET	●		●	
MISSION PECULIAR GROUND FACILITY SOFTWARE AND PROCEDURES		●	●	
TMS	●			●
TMS COMMAND SET	●			●
TMS AUTOMATED MAGAZINE EXCHANGE SYSTEM	●		●	

KEY BENEFITS OF TDM 5 SERVICING OF FREE FLYING MATERIALS PROCESSING PLATFORM

The overall benefit of this TDM is to develop and demonstrate operational procedures that will be essential in future space processing and space industrialization projects and will have to be performed in a routine semi-automatic or fully automatic mode, under remote control from the space station. In order to make space processing practical and economically attractive the planned periodic and routine resupply of raw material and harvesting of finished products may be carried out frequently and without a hitch.

The TD elements listed in this chart involve the essential steps toward development/demonstration of this new technology aboard the space station and on free-flying platforms tended remotely by the space station. Utilization of the Teleoperator (TMS) is a critical element in this chain of activities. The space station provides the appropriate operational base for practicing TMS deployment, remote control and retrieval. A simulated or realistic free-flying materials processing platform will serve as the object of validating the technology and debugging any procedures and support equipment that have not reached a fully mature state of development. As such, the shake down may require an extended time period, possibly supported by rework or modifications of critical equipment on the ground.

KEY BENEFITS OF TDM 5
SERVICING MATERIALS PROCESSING PLATFORM

TECHNOLOGY DEVELOPMENT ELEMENT	MISSION BENEFIT(S)
1. DEMONSTRATE CHANGEOUT OF PROCESSING MODULES OR SAMPLE MAGAZINES a. IN HANDS-ON MODE b. !N HANDS-OFF MODE	• ESTABLISHES ROUTINE OPERATING PROCEDURES FOR MODULE AND SAMPLE CHANGEOUT, ADVANCING FROM HANDS-ON TO HANDS-OFF MODES. INITIALLY WITH EVA CREW MEMBER STANDING BY IN HANDS-OFF MODE (RMS UTILIZATION)
2. TMS RETRIEVEAL/REDEPLOY-MENT OF FREE-FLYING PROCESSING PLATFORM (PP) FOR SERVICING ON-BOARD SS	• DEMONSTRATES TMS USE IN PP TRANSFER (SEE TDM 4, NO. 4) • DEMONSTRATES/ESTABLISHES ROUTINE ON-BOARD PP-SERVICING
3. IN-SITU (OFF-BOARD) PP SERVICING BY TMS BY CHANGE-OUT OF a. ENTIRE PROCESS MODULES b. SAMPLE MAGAZINES	• DEMONSTRATES IN-SITU PP SERVICING BY TMS FOR FUTURE USE ON OPERATIONAL MISSION; MINIMIZES INTERRUPTION OF PP PRODUCTION CYCLES • DEMONSTRATES MISSION PROFILE SEQUENCE OF PERIODIC PP ORBIT REBOOST OPERATIONS BY TMS (LIVINGSTON SEQUENCE, JSC) ALONG WITH SAMPLE CHANGEOUT

OVERALL TDM BENEFIT – DEVELOPS AND DEMONSTRATES OPERATIONAL PROCEDURES ESSENTIAL TO ROUTINE REMOTE (IN-SITU) MPS PLATFORM SERVICING BY TMS

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Task 3 Programmatic Analysis

This section of the final report is organized as shown by this chart. The Introduction and Summary first briefly repeats the scope, flow and output of Task 3 as outlined in the study plan. The results of Tasks 3.1 and 3.2 are then recapped in combined and summary fashion for the five TDMs being studied in detail. Tasks 3.1 and 3.2 are then treated together, presenting study results TDM by TDM. In this way each TDM is presented on a stand alone basis. Finally, the environmental analysis is summarized.

TASK 3 INTRODUCTION AND SUMMARY

TASK 3.1 PLANS AND SCHEDULES

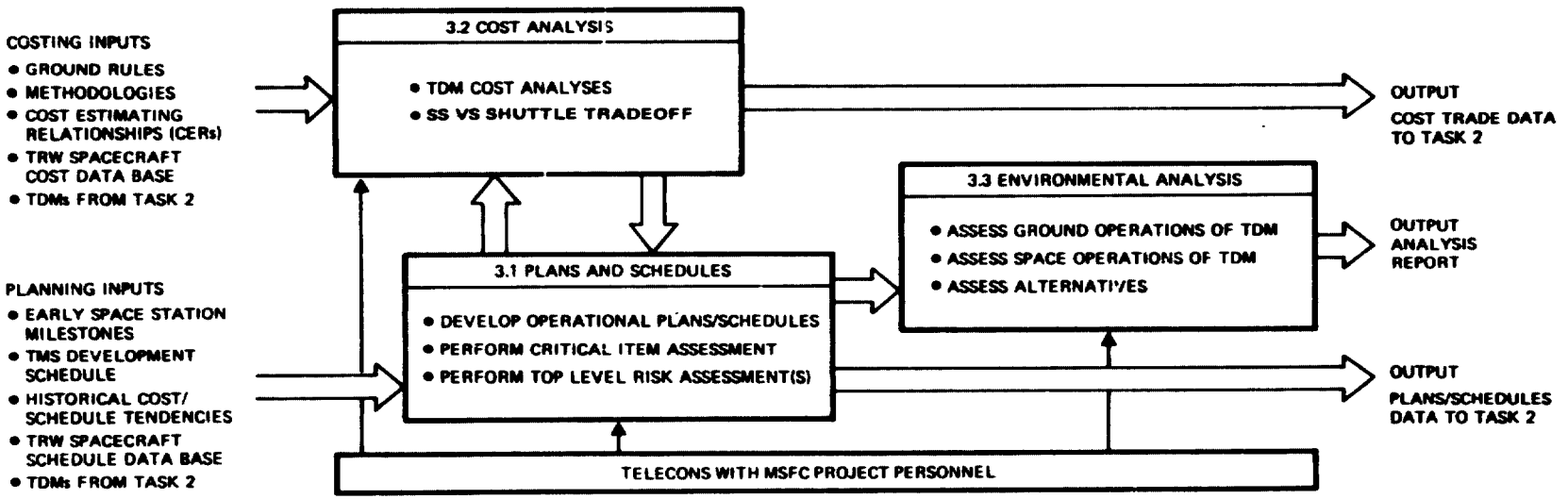
TASK 3.2 COST ANALYSIS

TASK 3.3 ENVIRONMENTAL ANALYSIS

TASK 3 PROGRAMMATIC ANALYSIS - LOGIC FLOW

This chart shows the logic flow for Task 3 Programmatic Analysis undertaken as required by the Study Plan. The cost analysis is an iterative process with Task 2 where Task 2 provides the information as required to fit the cost model. TRWs cost data base and other cost models such as RCA PRICE are used to generate the cost estimates. Data was generated to evaluate the benefit of conducting the TDM using the space station versus performing the TDM using the STS or another approach. Integration of the TDM into a composite schedule including precursor technology development activities is a part of this task. Identification of critical items is a part of Task 2. However, incorporation into a risk assessment is part of this task. The environmental analysis is prepared as a part of this task to assure that a contemplated TDM is not at risk of being disapproved because of a potential impact on the ground or space environment.

TASK 3. PROGRAMMATIC ANALYSIS - LOGIC FLOW



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This chart summarizes Task 3 and shows the expected outputs from the Task. All of the expected cost, schedule, trades, critical item and risk assessments are included in this section of the final report. These aspects of Task 3 are grouped for each TDM. The environmental assessment is only summarized in this section and is detailed in a separate report, "Environmental Analysis, (DR-5)" dated 7 January 1983.

TASK 3 FLOW - PROGRAMMATIC ANALYSIS

SUBTASK OBJECTIVES	INPUTS	APPROACH	EXPECTED OUTPUTS
3.1 PLANS AND SCHEDULES • PLANNING AND SCHEDULING DATA FOR TASK 2 TRADE ANALYSES • END-TO-END OPERATIONAL PLAN/ SCHEDULE FOR THE RECOMMENDED TDM(s) • CRITICAL ITEM AND RISK ASSESSMENTS IN SUPPORT OF TASK 2 TRADES	TDM(s) FROM TASK 2, TRW HISTORICAL SPACECRAFT SCHEDULE DATA, TMS DEVELOPMENT SCHEDULE, MSFC EARLY SPACE STATION MILESTONES, COST ESTIMATES FROM SUBTASK 3.2	1. PREPARE END-TO-END PLAN(S) 2. PREPARE PLAN SCHEDULE(S) 3. CONDUCT CRITICAL ITEM ASSESSMENT 4. CONDUCT TDM(s) RISK ASSESSMENT	SCHEDULES, PLANS, RESULTS OF CRITICAL ITEMS AND RISK ASSESSMENTS FOR TDMs
3.2 COST ANALYSIS • COST ESTIMATES OF TDM IMPLEMENTATION • SHUTTLE VERSUS EARLY SPACE STATION SATELLITE SERVICING TRADEOFF	TDM(s) FROM TASK 2. TRW HISTORICAL SPACECRAFT COST DATA, ESTIMATING RELATIONSHIPS (CERs), PLANS AND SCHEDULE FROM SUBTASK 3.1	1. OBTAIN COSTING PARAMETERS 2. APPLY COSTING MODELS 3. PREPARE TDM COST ANALYSIS	COST ESTIMATES FOR EACH TDM. TRADEOFF OF SHUTTLE vs EARLY SPACE STATION FOR EACH TDM
3.3 ENVIRONMENTAL ANALYSIS • AFFECT OF TOTAL TDM(s) ON GROUND AND SPACE ENVIRONMENT	TDM(s) SELECTED, PRELIMINARY OPERATIONAL PLANS	1. ASSESS GROUND OPERATIONS 2. ASSESS SPACE OPERATIONS 3. IDENTIFY ALTERNATIVES 4. ASSESS ALTERNATIVES	ENVIRONMENTAL ASSESSMENT REPORT

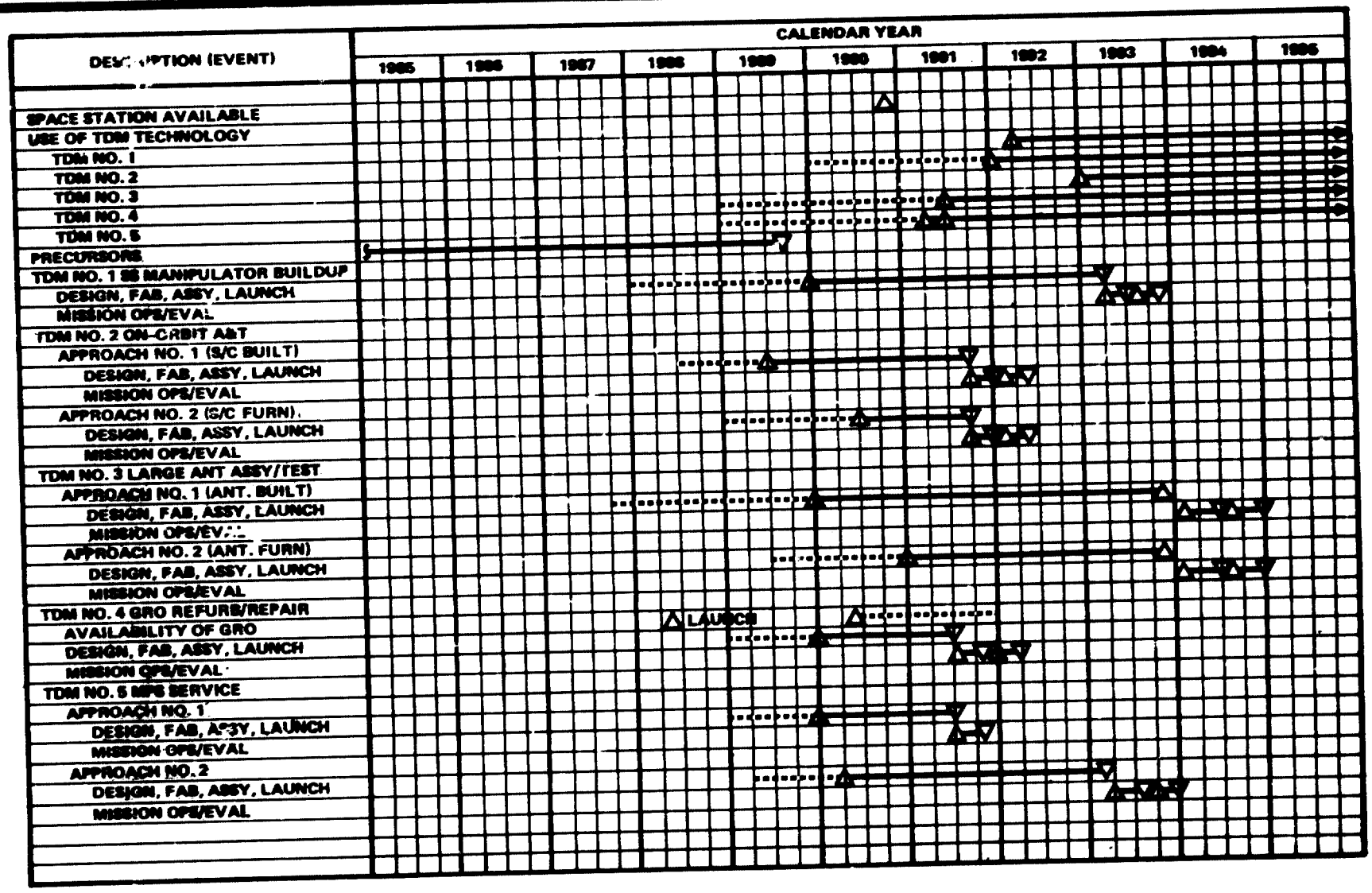
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SUMMARY SCHEDULE - TDMs

This is a composite schedule for the five TDMs detailed by TRW. TDMs 2, 4 and 5 can occur in approximately the same timeframe - in 1991 shortly after the early space station becomes operational. TDM 4 involving GRO has the most critical schedule since its mission by current schedules is completed in the second quarter of calendar '90 - about six months before IOC of an initial space station. TDM 1 depends upon the growth cycle planned for the space station and TRW's space station study tentatively shows growth to incorporate a mobile manipulator capability occurring in 1993. TDM 3 is dependent upon large structure and large antenna technologies and the projected need for that technology.

This composite schedule also gives some feel for the relative lead time required for the TDMs. TDM 4 requires the least lead time; since it utilizes GRO, a funded and planned program. TDM 3 requires the longest, again, for technology reasons.

SUMMARY SCHEDULE - TDMs



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SUMMARY CRITICAL ITEM AND RISK ASSESSMENT

This chart summarizes the critical items and a qualitative assessment of the risk for each line item. Subsequent charts for each TDM are more detailed, showing whether the risk primarily impacts schedule, cost or performance. The charts for each TDM also list additional line items not shown on this summary chart. The highest risk centers around TDM 3 "Large Antenna Structure Deployment." A great deal of new technology, as yet unproven in a space environment, is involved in TDM 3. Achieving both the required technology and the hardware for an on-orbit experiment involves substantial risk. In absolute terms the risk to the TDM is greatest if the TDM bears the risk of experimental hardware development and manufacture.

SUMMARY - CRITICAL ITEM AND RISK ASSESSMENT

TRW

- THIS CHART LISTS SOME OF THE KEY CRITICAL ITEMS AND RELATIVE RISKS

CRITICAL ITEM	TDM 1	TDM 2	TDM 3	TDM 4	TDM 5	COMMENT
1. STS DELAY	○	○	○	○	○	PRIMARILY COST/SCHEDULE RISKS
2. TIME TO PERFORM TDM ON-ORBIT	◑	◑	◑	◑	◑	MODERATE RISK – ALL TDMs
3. SPACE STATION AVAILABILITY/CAPABILITY	○	◑	◑	◑	◑	
4. TMS AVAILABILITY	–	–	◑	◑	◑	UNAVAILABILITY CURTAILS OBJECTIVES – PARTICULARLY TDM-5
5. TDM EQUIPMENT DESIGN	○	◑	●	○	○	PRIMARILY COST/SCHEDULE RISKS
6. TRACK SYSTEM AVAILABLE	◑	–	–	–	–	TDM-1
7. SIMULATED SPACECRAFT ADEQUATE	–	◑	–	–	–	TDM-2
8. TECHNOLOGY AVAILABLE	◑	○	●	○	◑	TDM NO. 3 DEPENDS HEAVILY ON PRECURSOR TECHNOLOGIES

○ LOW RISK ◑ MODERATE RISK ● HIGH RISK

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The early space station provides several broad and several specific advantages over the STS for conduct of these TDMs as shown on this chart. These are some of the same advantages favoring a space station as identified in our space station study for NASA Headquarters.

SUMMARY TRADES – EARLY SPACE STATION VS STS

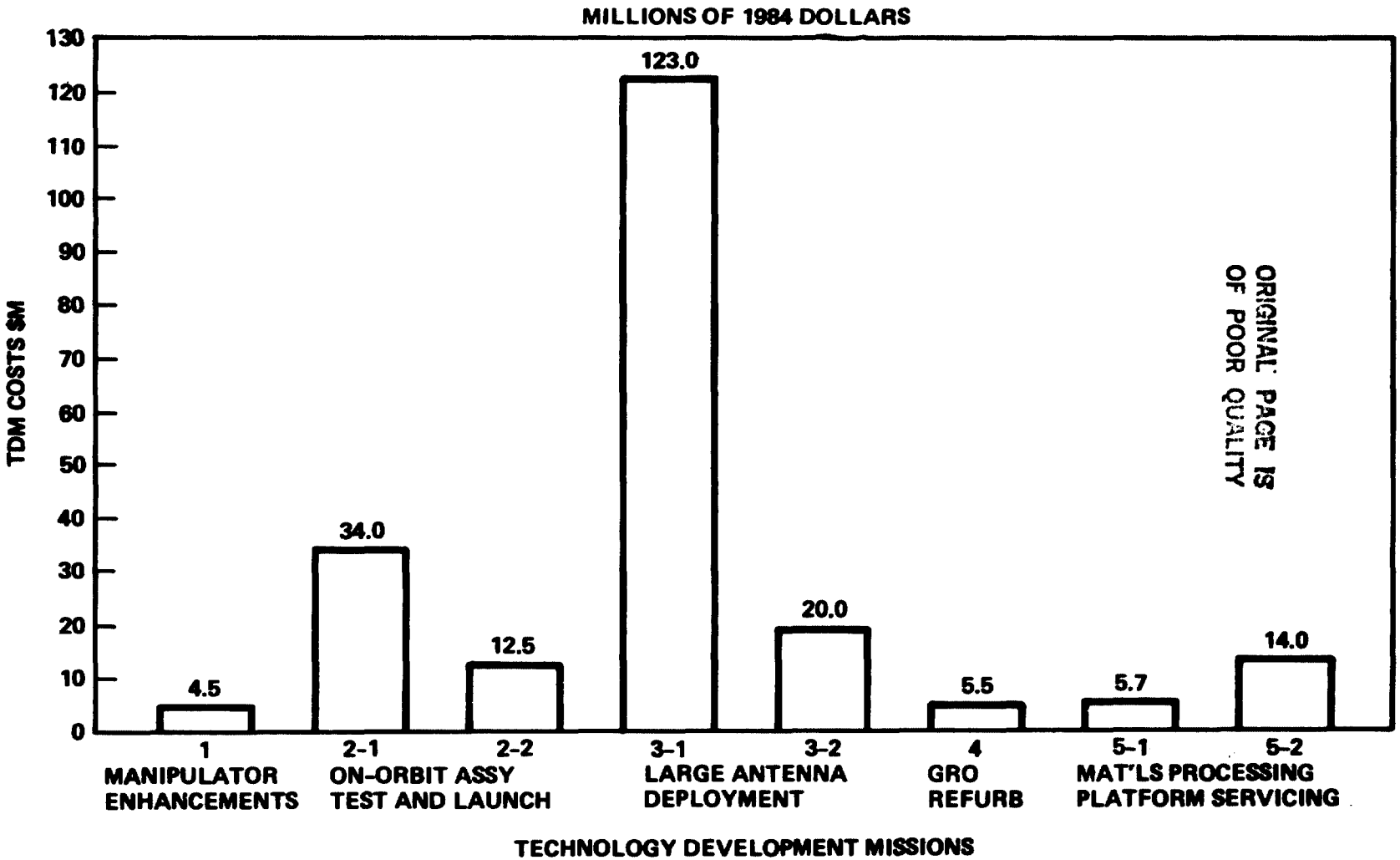
DESCRIPTION	ADVANTAGE		COMMENT
	STS	SS	
COMMON – ALL TDMs			
TIME ON-ORBIT		√	STS NOT TIED UP FOR TEST. MORE NONCONTIGUOUS TEST TIME AVAILABLE
STS TRANSPORTATION COSTS		√	MINIMIZED WITH OPTIMUM MANIFESTING. SUPPORT EQUIPMENT FOR CONTINUING USE LEFT IN PLACE
STORAGE		√	FLEXIBILITY IN STORING PARTS
RETURN EXPERIMENT TO GROUND	√		QUICKEST TURN-AROUND FOR GROUND REWORK
UNIQUE			
ANTENNA SIZE (TDM-3)		√	CAN BE LARGER THAN ON STS. CAN BE SALVAGED COMPARED TO GEO
GRO END OF LIFE (TDM-4)	√		GRO MAY REQUIRE DEORBITING BEFORE SPACE STATION IS READY
FLEXIBILITY OF HARVESTING/ REPLENISHMENT SCHEDULES (TDM-5)		√	SPACE STATION SUITED AS WAY STATION FOR OPTIMUM PRODUCTION OF MATERIALS IN SPACE
SPACE ENVIRONMENT (TDM-2)		√	ACTUAL TEST IN SPACE ENVIRONMENT FEASIBLE

COMPARISON OF TECHNOLOGY DEVELOPMENT MISSION COSTS

This chart provides a comparison of the costs for each proposed TDM including alternative approaches for TDMs 2, 3 and 5. The costs for TDMs 1, 4 and 5 are modest relative to 2 and 3. The largest TDM cost occurs for Approach 1 of TDM 2, where a 60 meter antenna must be constructed. If a large antenna is already available for TDM 3, then the cost is lower. This cost is significantly larger than TDMs 1, 4 and 5 since the TDM is still relatively complex even if the antenna is available.

The cost of TDM 2 is most for Approach 1 where an experimental spacecraft is built. If the satellite is available from an existing program, then the cost will be reduced by more than 60%. This is still above the costs of TDM 1, 4 and 5 (Approach 1) but below Approach 2 of TDM 3 and Approach 2 of TDM 5.

COMPARISON OF TECHNOLOGY DEVELOPMENT MISSION COSTS



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TASK 3.1 PLANS AND SCHEDULES AND TASK 3.2 COST ANALYSIS

These two subtasks of Task 3 Programmatic Analysis are combined and reported together for each of the five TDMs being defined in detail.

TASK 3 INTRODUCTION AND SUMMARY

TASK 3.1 PLANS AND SCHEDULES

TASK 3.2 COST ANALYSIS

TASK 3.3 ENVIRONMENTAL ANALYSIS

COSTING ROUND RULES AND ASSUMPTIONS
APPLICABLE TO ALL TECHNOLOGY DEVELOPMENT MISSIONS

These ground rules and assumptions characterize the cost estimates of all proposed TDMs. All cost estimtes are in 1984 dollars and exclude contractor fees. All TDMs will require space station support in terms of equipment and crew time and this support is assumed to be available at no cost to the TDM. Similarly, STS costs are not included in these estimates and NASA facilities are assumed available at no cost to the TDM where required for ground tests.

A low cost approach has been taken in developing the estimates through use of the protoflight approach and assuming minimum redundancy in hardware development. Existing designs are assumed to be available for most required hardware with only a minimum level of modifications required for TDM use. For example, the spacecraft subsystems design and test costs in TDM 2 are estimated to be 50% of the production unit costs where this factor is normally between 200-300% of the unit production cost.

The costing methodology is based upon the use of TRW cost estimating relationships (CERs), the RCA PRICE program, analogy with past TRW experience and estimating labor hours for a specific task or level of effort.

COSTING GROUND RULES AND ASSUMPTIONS APPLICABLE TO ALL TECHNOLOGY DEVELOPMENT MISSIONS

- ALL COSTS ARE IN 1984 DOLLARS
- COSTS EXCLUDE CONTRACTOR FEES
- SPACE STATION CAPABILITIES AND CREW TIME ARE AVAILABLE TO THE TDM AND NOT INCLUDED IN COST ESTIMATES
- SPACE STATION GROUND STATION FACILITIES AVAILABLE AS REQUIRED WITHOUT COST
- SPACE TRANSPORTATION COSTS ARE EXCLUDED
- PROTOFLIGHT DEVELOPMENT IS ASSUMED WHERE APPLICABLE
- MINIMUM REDUNDANCY IN HARDWARE
- NASA's FACILITIES ARE AVAILABLE FOR GROUND SIMULATION TESTING AT NO COST TO THE TDM
- COSTS ARE BASED UPON TRW CER's, RCA PRICE AND ANALOGY TO UNMANNED SPACE HARDWARE

TECHNOLOGY DEVELOPMENT MISSIONS
WORK BREAKDOWN STRUCTURE

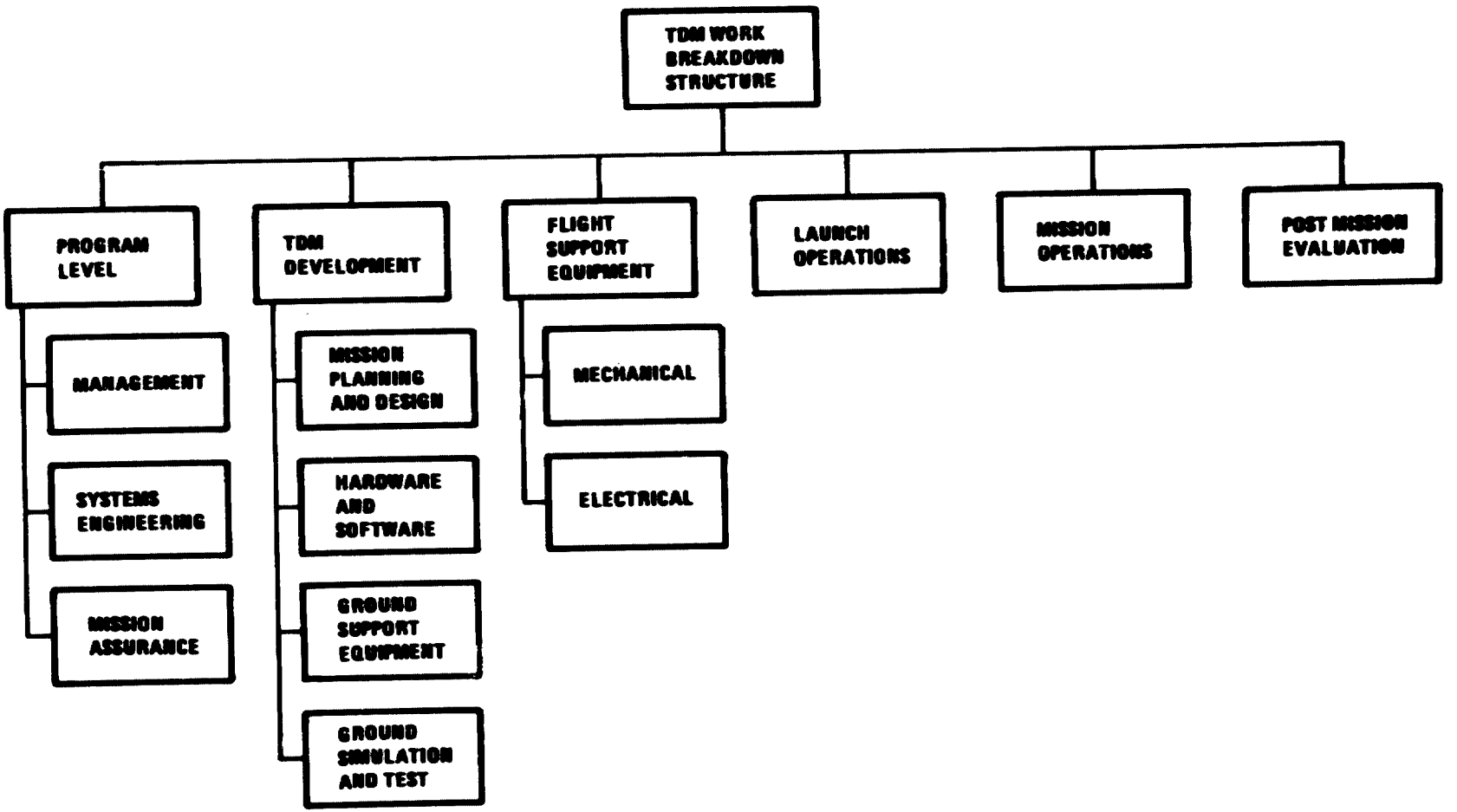
The work breakdown structure (WBS) for each TDM is basically the same with the generic elements shown in the chart. Variations may occur in each TDM at the lowest WBS element shown. For example, in Approach 1 of TDM 2, an experimental spacecraft is to be built. In this element, the hardware is further subdivided into spacecraft subsystems. In the following cost results, TDM-peculiar WBS will be provided as required.

The program level elements include all management, system engineering and mission assurance tasks related to the overall TDM. TDM development includes the mission planning and design, hardware and software development, ground support equipment and ground simulation and test. Flight support equipment is separated as a category since this support hardware is to be located in the orbiter or the space station.

Launch operations includes all planning, transportation and integration activities to support the mission launch. Mission operations encompasses all costs incurred during the conduct of the mission, particularly at the ground operation centers.

Post mission evaluation consists of processing the TDM data, analyzing and evaluating the TDM data and activity, drawing conclusions and recommendations and providing appropriate documentation.

TECHNOLOGY DEVELOPMENT MISSIONS WORK BREAKDOWN STRUCTURE



Task 3.1 and Task 3.2 are further subdivided as shown on this chart. Task 3.1 covers programmatic schedules, critical item assessment and risk assessment. Task 3.2 covers 1) the tradeoff between the early space station and the shuttle and 2) the cost analysis of each TDM. This section of the final report addresses each of these items TDM by TDM.

- SUBTASKS AND SUBTASK TOPICS COVERED FOR EACH TDM:

TASK 3.1 PLANS AND SCHEDULES

- SCHEDULE
- CRITICAL ITEM ASSESSMENT
- RISK ASSESSMENT

TASK 3.1 COST ANALYSIS

- EARLY SPACE STATION VS. SHUTTLE TRADEOFF
- TDM COST ANALYSIS

- TDM ADDRESSED ON THE FOLLOWING PAGES

TDM 1 BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY

TDM 2 ON-ORBIT SPACECRAFT ASSEMBLY, TEST AND LAUNCH

TDM 3 LARGE ANTENNA STRUCTURE DEPLOYMENT

TDM 4 SERVICE/REFURBISH SATELLITE (GRO)

TDM 5 SERVICING OF FREE-FLYING MATERIALS PROCESSING PLATFORM

TDM-PECULIAR GROUND RULES AND ASSUMPTIONS

TDM #1 - BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY

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- THE TDM IS ASSUMED TO BE AN ADDITIONAL TASK FOR THE SPACE STATION CREW DURING THE IMPLEMENTATION OF THE MOBILE MANIPULATOR SYSTEM. SPECIAL TDM EQUIPMENT ARE DEVELOPED AS REQUIRED.

- SPACE STATION CAPABILITIES ASSUMED TO BE AVAILABLE FOR TDM AND EXCLUDED FROM TDM COST ESTIMATES:

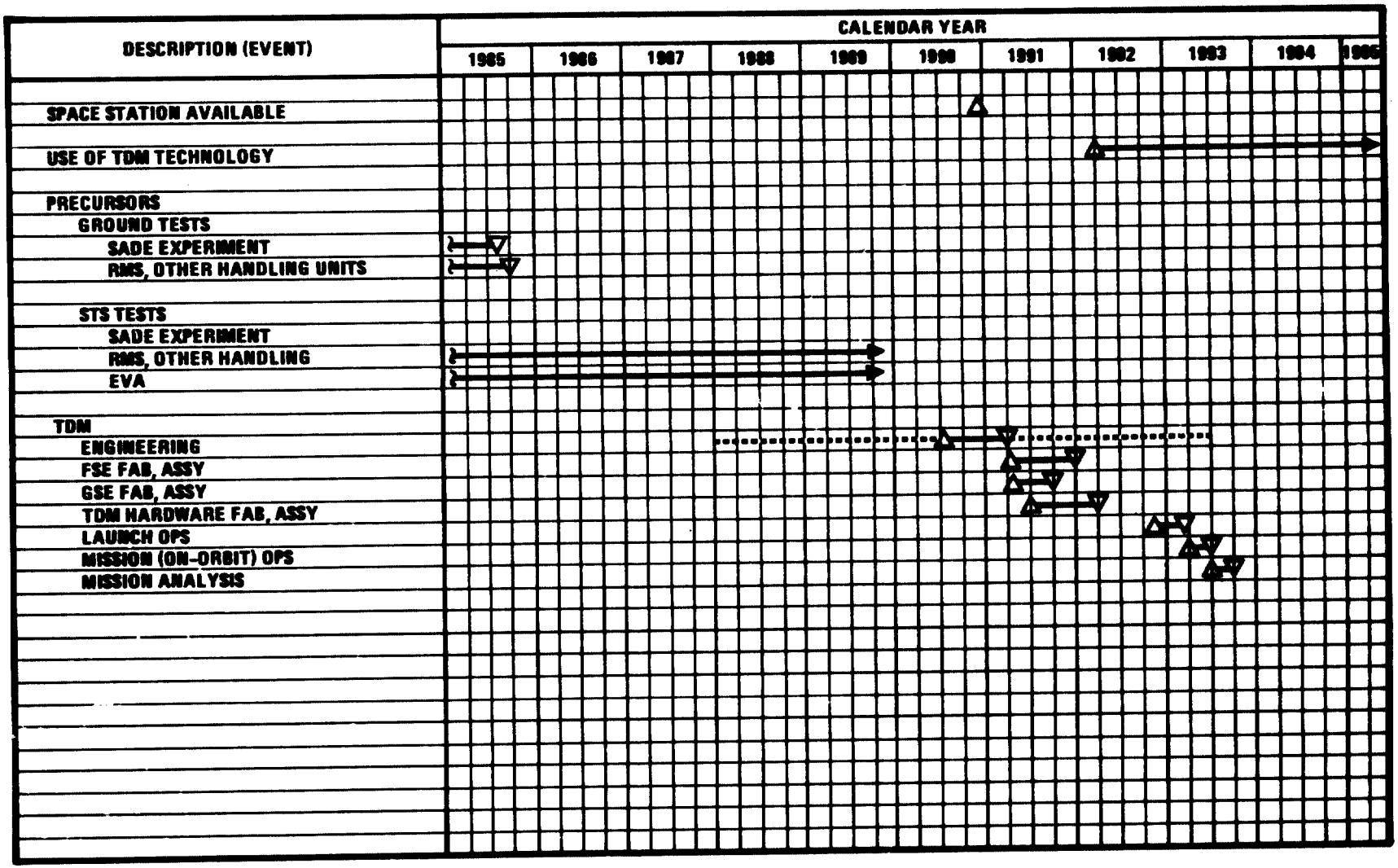
  - FIXED REMOTE MANIPULATOR ARM
  - TRACK SYSTEM SEGMENTS
  - RMS CONTROL SYSTEM

SCHEDULE - TDM 1 BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY

The schedule for this TDM can be relatively short. The schedule of this chart shows an elapsed time of about 24 months, and much of this time is low level to assure coordination with the related hardware and software upon which this TDM depends. The actual on-orbit mission operations reflect a tentative schedule for the addition of this capability to the space station. Several precursors are shown in the schedule: 1) the structural assembly demonstration experiment (SADE) is a specific, planned experiment. Ground and STS experiments relating to the RMS, other handling units and EVA are not specifically detailed but are expected to be continuing in the years before the space station.

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SCHEDULE - TDM NO. 1 BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY



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For this TDM, the number of critical items and their associated risk is relatively low. One of the greater risks in that precursor work for specific technology elements has not been completed in time to support the TDM. This could cause the scope of the TDM to be curtailed. This TDM is dependent upon a specific space station growth item - the mobilizing of the manipulator by adding a track system. Some risk exists if that growth item is significantly altered in time or concept. However, other construction-type growth items could be substituted and used to implement the TDM objectives.

CRITICAL ITEM AND RISK ASSESSMENT
TDM NO. 1

TRW

NO.	ITEM	RISK			COMMENT
		COST	PERF	SCHED	
1	STS DELAY	○	–	○	
2	TIME TO PERFORM OPERATION ON-ORBIT	◑	–	◑	TIME UNDERESTIMATED
3	SS AVAILABILITY/CAPABILITY	○	–	◑	NOT AVAILABLE AS REQUIRED
4	TDM EQUIP/DESIGN	◑	◑	◑	INADEQUATE OR LATE
5	TRACK SYSTEM AVAILABILITY	◑	–	◑	TRACK SYSTEM, UPON WHICH TDM IS BASED, IS DELAYED
6	LOGISTICS	◑	–	◑	SUPPLIES, SPARES, OTHER NEEDS NOT AVAILABLE
7	TECHNOLOGY ELEMENTS	–	◑	–	DELAYED OR NOT AVAILABLE AT TIME OF EXPERIMENT

○ LOW RISK ◑ MODERATE RISK ● HIGH RISK

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EARLY SPACE STATION VS STS TRADEOFF TDM NO. 1

NO.	DESCRIPTION	ADVANTAGE		COMMENT
		STS	SS	
	THERE IS NO APPLICABLE TRADE BETWEEN CONDUCT OF THIS TDM ON THE STS VERSUS CONDUCT ON THE SPACE STATION. IT IS SPECIFICALLY DESIGNED TO USE THE EARLY SPACE STATION BUILD-UP TO LEARN ABOUT AND VERIFY ASSUMPTIONS APPLICABLE TO SPACE STATION EVOLUTION			

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COST SUMMARY - TDM #1

The total cost for the TDM related to the buildup of the space station manipulator capability is 4.5 million dollars. The major cost item is 2.4 million dollars for TDM development. Since most of the hardware for the TDM will be developed under space station costs, very little will be necessary in the way of new hardware for the TDM itself. The TDM is essentially a task added to buildup activity for the space station track and mobile manipulator system. The total TDM development cost is relatively evenly distributed among planning, hardware, software and testing costs.

COST SUMMARY - TDM #1

WBS ITEM	COST MILLIONS OF 1984 DOLLARS
PROGRAM LEVEL	0.75
TDM DEVELOPMENT	2.4
FLIGHT SUPPORT EQUIPMENT	0.5
LAUNCH OPERATIONS	0.15
MISSION OPERATIONS	0.5
POST MISSION EVALUATION	0.24
TOTAL	4.54

TASK 3.1 AND TASK 3.2

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- SUBTASKS AND SUBTASK TOPICS COVERED FOR EACH TDM:

  TASK 3.1 PLANS AND SCHEDULES
  - SCHEDULE
  - CRITICAL ITEM ASSESSMENT
  - RISK ASSESSMENT

  TASK 3.2 COST ANALYSIS
  - EARLY SPACE STATION VS. SHUTTLE TRADEOFF
  - TDM COST ANALYSIS

- TDM ADDRESSED ON THE FOLLOWING PAGES

  TDM 1 BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY

  TDM 2 ON-ORBIT SPACECRAFT ASSEMBLY, TEST AND LAUNCH

  TDM 3 LARGE ANTENNA STRUCTURE DEPLOYMENT

  TDM 4 SERVICE/REFURBISH SATELLITE (GRO)

  TDM 5 SERVICING OF FREE-FLYING MATERIALS PROCESSING PLATFORM

TDM SPECIFIC GROUND RULES AND ASSUMPTIONS
TDM #2 ON-ORBIT ASSEMBLY, TEST & LAUNCH OF SPACECRAFT

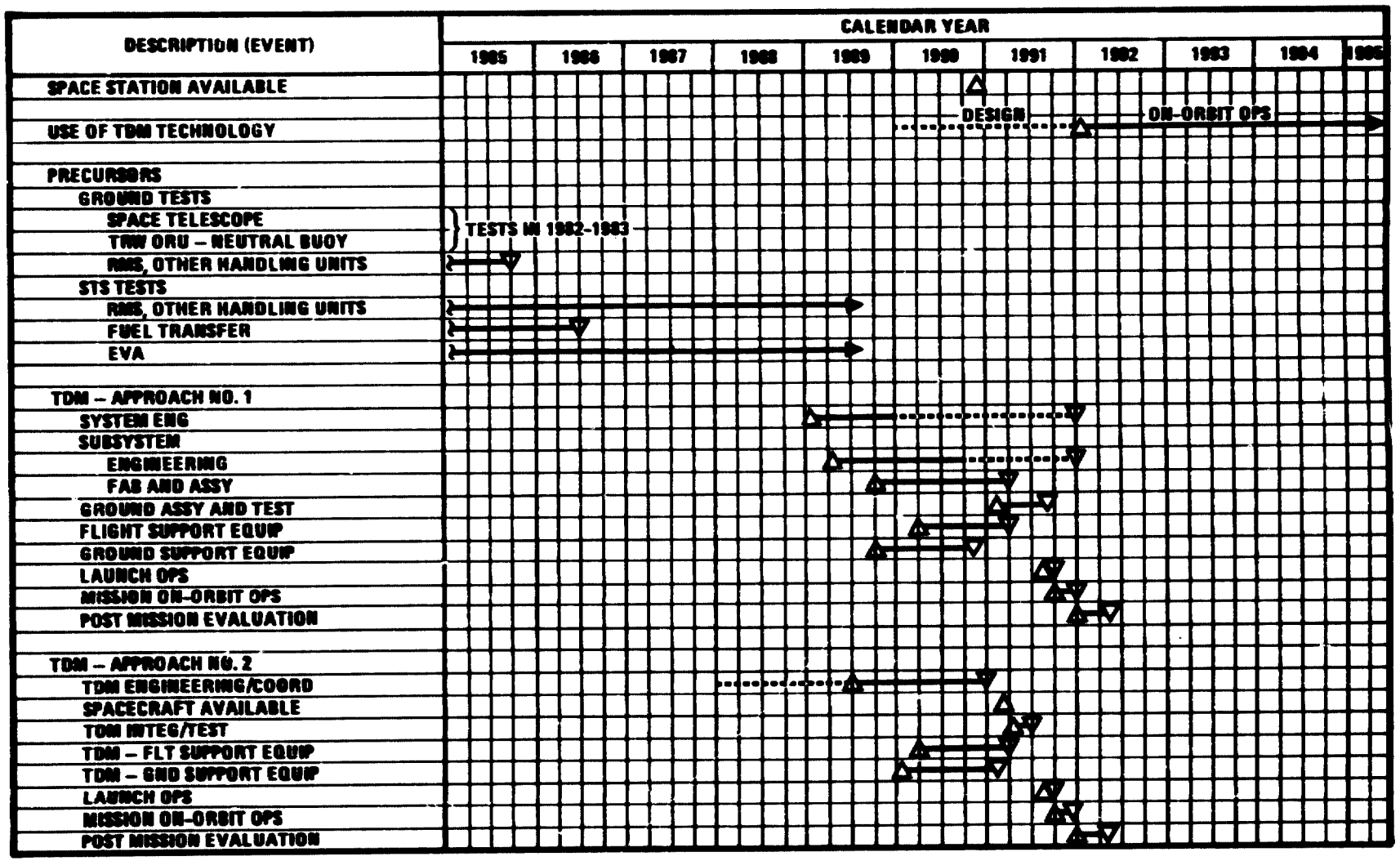
- TWO COST AND SCHEDULING APPROACHES TAKEN:
  1) AN EXPERIMENTAL SPACECRAFT IS DESIGNED AND BUILT FOR THE TDM. LAUNCH FROM THE SPACE STATION MAY BE DELETED AS ONE OF THE TEST OBJECTIVES.
  2) AN EXISTING PROGRAM HAS A SPACECRAFT THAT SATISFIES THE TDM REQUIREMENTS AND THE TDM IS AN ADDITIONAL TASK ADDED TO THE PROGRAM.

- SPACE STATION CAPABILITIES ASSUMED AVAILABLE FOR THIS TDM AND EXCLUDED FROM TDM COST ESTIMATES:
  - -- ORBIT TRANSFER CAPABILITY
  - -- PROPELLANT
  - -- MISSION TARGETING COMPUTER
  - -- ASSEMBLY TOOLS

SCHEDULE - TDM 2 SATELLITE ASSEMBLY, TEST AND LAUNCH

There are two schedules for this TDM. The schedule for Approach 1 is the longer one because design and manufacture of the simulated spacecraft is involved. A span of approximately two years is required from start to launch. All activity associated with design, manufacture and test of this simulator is shown. Ground support equipment and flight support equipment is also scheduled. The schedule for Approach 2 where the spacecraft is furnished requires a TDM schedule of about 20 months and the front end portion of the time is relatively low level effort to maintain coordination with the supplier of the spacecraft which is being used for the TDM. Approach 2 assumes that some ground and flight support equipment unique to the TDM is designed and built and used to support TDM-unique functions engineered into the spacecraft and the space station. The time spans for these activities are shown in the Approach 2 schedule.

SCHEDULE - TDM NO. 2
SATELLITE ASSEMBLY, TEST AND LAUNCH



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CRITICAL ITEM AND RISK ASSESSMENT - TDM 2

For this TDM, a number of critical items exist which are common to both of the approaches which are scheduled and costed. STS delay, logistics inadequacies, under estimates of on-orbit time required, and SS availability are risks applicable to both approaches and, for that matter, to all of the TDMs being studied. The interface between the SS and the spacecraft is of concern because of the complex levels of testing of the spacecraft. Test interfacing (as one of the technological areas related to this TDM) requires a higher degree of automation, higher rates and greater flexibility than currently in use to assure viability of assembly and test on-orbit. The most critical item with the greatest risk unique to Approach 1 is perceived to be the adequacy of the simulated spacecraft. Extensive, high fidelity simulation drives cost upward; minimized simulation may be low cost but risks technical inadequacy to properly test the hypothesis that assembly and test on-orbit is a viable concept. Two items are unique to Approach 2. The spacecraft used for the TDM is delayed or not available or the spacecraft program places some reliance on the validity of the TDM premise which is not validated and therefore puts the spacecraft project in jeopardy.

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CRITICAL ITEM AND RISK ASSESSMENT
TDM NO. 2

NO.	ITEM	RISK			COMMENT
		COST	PERF	SCHED	
1	COMMON – BOTH APPROACHES				
2	SCHEDULE TO LAUNCH	◑	–	◑	SCHEDULE TO LAUNCH MISSED WITH PROGRAMMATIC AND STS TRANSPORT COST IMPACT
3	STS DELAY	○	–	○	
4	LOGISTICS	◑	–	◑	SUPPLIES, SPARES, OTHER NEEDS NOT AVAILABLE
5	TIME TO PERFORM A&T ON ORBIT	◑	–	◑	TIME UNDERESTIMATED
6	INTERFACE	○	◑	○	DESIGN, VERIFICATION ERROR
7	SS AVAILABILITY/CAPABILITIES	○	–	◑	NOT AVAILABLE AS REQUIRED
8	TECHNOLOGY ELEMENTS	–	◑	–	PRECURSORS NOT COMPLETED
9	UNIQUE TO APPROACH NO. 1				
10	REPRESENTATION	◑	●	–	SIMULATOR FOR TDM DOES NOT ADEQUATELY REPRESENT OPERATION
11	UNIQUE TO APPROACH NO. 2				
12	SPACECRAFT FOR TDM	◑	–	◑	SPACECRAFT USED BY TDM NOT AVAILABLE OR DELAYED
13	LAUNCH AND TARGETING	◑	◑	–	INADEQUATE, PERHAPS CAUSES LOSS OF MISSION
14	A&T ON-ORBIT	◑	●	◑	CONCEPT NOT VIABLE – IMPACTS MISSION SUCCESS

○ LOW RISK ◑ MODERATE RISK ● HIGH RISK

EARLY SPACE STATION VS. STS TRADEOFF - TDM 2

This TDM requires more time on orbit than is usually considered to be available in a single orbiter flight. Also the time required is not always contiguous time. Non-contiguous time can be more efficiently provided by the space station. One of the benefits of assembly and test on orbit is to permit spacecraft to be larger in diameter, length or total volume than a single shuttle flight can carry. A scenario for such an "oversize" spacecraft is to use the space station for assembly and storage of the initial parts until the balance of parts are delivered by a subsequent shuttle flight. The alternate scenario of leaving a partial spacecraft stored on orbit awaiting a subsequent orbiter flight is less viable. If the space station is ultimately used for such assembly and test as well as servicing operations it is desirable that the capability for such operations be put in place and verified via this TDM.

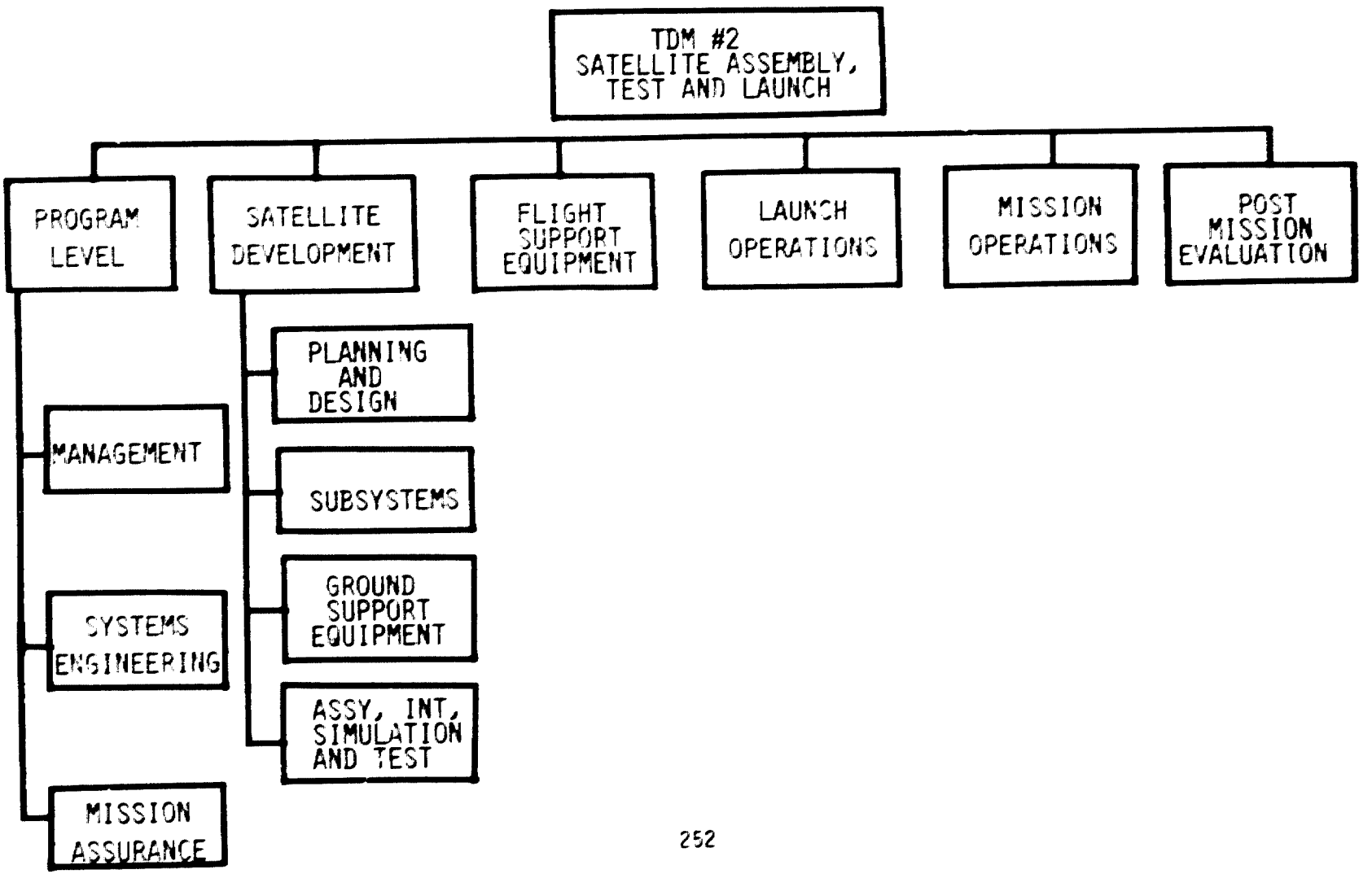
EARLY SPACE STATION VS STS TRADEOFF
TDM NO. 2

NO.	DESCRIPTION	ADVANTAGE		COMMENT
		STS	SS	
1.	TIME ON-ORBIT		√	STS AS "FREIGHTER" TO AND FROM LEO IS NOT TIED UP CONDUCTING ON-ORBIT EXPERIMENTS. NON-CONTIGUOUS TIME IS MORE READILY AVAILABLE ON A SPACE STATION
2.	STS TRANSPORTATION COSTS		√	ITEMS FOR THIS TDM CAN BE MANIFESTED MORE EFFICIENTLY WITH OTHER STS CARGO
3.	AVAILABILITY OF UNIQUE SUPPORT EQUIPMENT		√	CARRIED TO ORBIT ONCE AND LEFT IN PLACE OR STORED FOR FUTURE USE
4.	AVAILABILITY OF GENERAL PURPOSE SUPPORT EQUIPMENT		√	RMS, CONSTRUCTION PLATFORM, ETC., AVAILABLE ON-ORBIT WITHOUT TRANSPORT TO ORBIT AND RETURN FOR EACH UNIQUE USE
5.	STORAGE		√	STORAGE OF PARTIAL SPACECRAFT AT A SPACE STATION IS MORE VIABLE THAN STORAGE ON-ORBIT
6.	SPACE ENVIRONMENTS		√	TIME TO TEST IN SPACE ENVIRONMENT CAN BE EXPLOITED

WORK BREAKDOWN STRUCTURE - TDM #2

The work breakdown structure for TDM #2 differs slightly from the prior described generic work breakdown structure. The variation is due to the requirement for a satellite capable of being assembled on-orbit. As seen in the accompanying chart, the satellite development box replaces the TDM development box to indicate the significance in the cost of a satellite. The satellite development portion of the work breakdown structure includes the TDM planning and design as well as the development of satellite subsystems and the assembly, integration and test of the subsystems into a complete spacecraft. This WBS is assumed to be the same for the two approaches taken in deriving the cost for this TDM. Approach #1 assumes that an entire satellite must be produced for this TDM. This satellite would include both the spacecraft bus and a simulated payload. The second approach assumes that a satellite has already been developed and the TDM would represent a task added to the assembly test and launch on-orbit of the satellite.

WORK BREAKDOWN STRUCTURES - TDM #2



COST SUMMARY - TDM #2

This chart presents a summary of the costs of TDM #2 for the two approaches taken in costing this TDM. Using Approach #1, where a total satellite is to be developed, the total cost is estimated to be 34.7 million dollars. In Approach #2, where a satellite is already assumed to be available for this TDM, the total cost will be 12.6 million dollars.

In Approach #1 the major cost is in the development of the satellite, which amounts to 23.8 million dollars. The total weight of the satellite, including the payload, is assumed to be 2,775 pounds; of which 1200 pounds represents the simulated payload. The performance capabilities of this satellite are assumed to be in the class of the TRW-built FLTSATCOM and TDRSS satellite. The cost estimates assume that very little new design will be required and minimum redundancy exists within individual subsystem elements.

Approach #2 assumes that the satellite has already been developed for a mission in which on-orbit assembly, test and launch will take place. The TDM then would represent an additional task to be added to the assembly, test and launch procedures. The major reduction is in the reduced cost associated with satellite development. The reduction is from 23.8 million dollars to 6.1 million dollars. Also, the program level cost associated with the TDM and satellite development has been reduced from 5.8 million dollars to 3.3 million dollars. The launch operations have been reduced in cost from 0.9 million dollars to 0.2 million dollars.

COST SUMMARY - TDM #2

MILLIONS OF 1984 DOLLARS

WBS ITEM	APPROACH #1	APPROACH #2
PROGRAM LEVEL	5.8	3.3
SATELLITE DEVELOPMENT	23.8	6.1
FLIGHT SUPPORT EQUIPMENT	2.5	1.3
LAUNCH OPERATIONS	0.9	0.2
MISSION OPERATIONS	1.5	1.5
POST MISSION EVALUATION	0.2	0.2
	34.7	12.6

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TASK 3.1 AND TASK 3.2

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- SUBTASKS AND SUBTASK TOPICS COVERED FOR EACH TDM:

TASK 3.1 PLANS AND SCHEDULES

- SCHEDULE
- CRITICAL ITEM ASSESSMENT
- RISK ASSESSMENT

TASK 3.2 COST ANALYSIS

- EARLY SPACE STATION VS SHUTTLE TRADEOFF
- TDM COST ANALYSIS

- TDM ADDRESSED ON THE FOLLOWING PAGES:

TDM 1 BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY

TDM 2 ON-ORBIT SPACECRAFT ASSEMBLY, TEST AND LAUNCH

TDM 3 LARGE ANTENNA STRUCTURE DEPLOYMENT

TDM 4 SERVICE/REFURBISH SATELLITE (GRO)

TDM 5 SERVICING OF FREE-FLYING MATERIALS PROCESSING PLATFORM

TDM-PECULIAR GROUND RULES

TDM #3 LARGE ANTENNA STRUCTURE DEPLOYMENT

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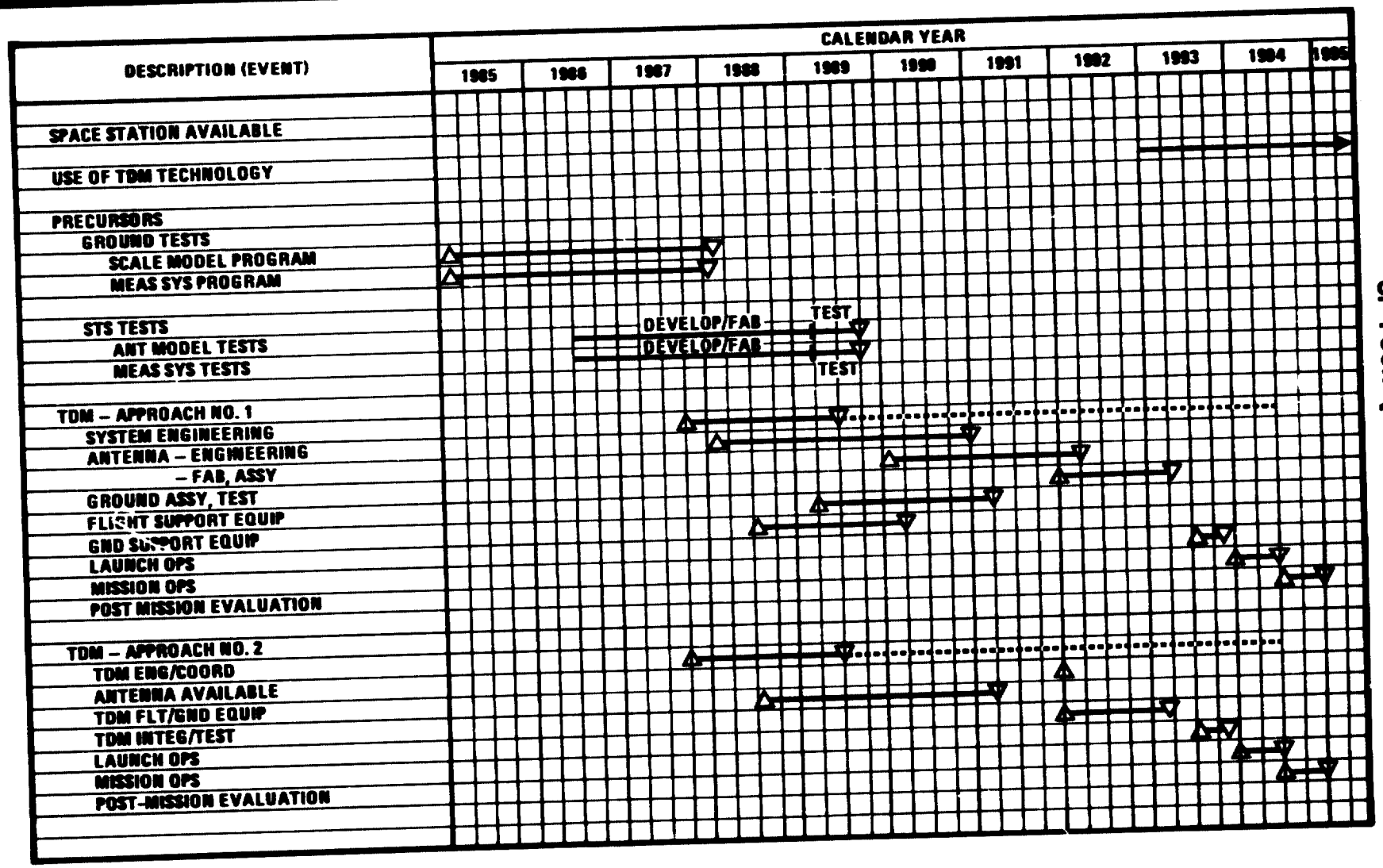
- TWO APPROACHES TO THE TDM WERE COSTED AND SCHEDULED:
  - AN EXPERIMENTAL 60 METER ANTENNA IS DESIGNED AND BUILT FOR THE TDM.
  - THE 60 METER ANTENNA IS DESIGNED AND BUILT FOR A SPECIFIC PROGRAM AND THE TDM IS AN ADDITIONAL TASK ADDED TO THE PROGRAM, AND ONLY THE COSTS RELATED TO THE ADDITIONAL TASKS ARE CHARGED TO THE TDM.
- SPACE STATION CAPABILITIES ASSUMED AVAILABLE FOR THIS TDM AND EXCLUDED FROM TDM COST ESTIMATES:
  - TELEOPERATOR MANEUVERING SYSTEM

SCHEDULE - TDM 3 LARGE ANTENNA STRUCTURE DEPLOYMENT

The two approaches outlined in the preceeding ground rules chart are scheduled. Both approaches are dependent upon significant precursor effort. Another alternative, not costed or scheduled, would be to use the antenna (approximately 15m) proposed for precursor experiments on the STS. Use of this antenna would reduce costs associated with Approach 1. It would also allow earlier scheduling. The schedule elapsed time for Approach 1 and Approach 2 are identical - about 6 years from start to launch. This time span is similar to schedules developed by TRW in Mobile Communication Satellite System Studies conducted by TRW for NASA/LRC. The level of effort in the early phases of Approach 2 is relatively low but assures compatibility of the TDM with the antenna system design.

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SCHEDULE - TDM NO. 3
LARGE ANTENNA STRUCTURE DEPLOYMENT



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For this TDM, the majority of critical items are common to both approaches. The highest risks relate to the key technologies involved including the basic construction approach, deploying, shaping, stiffening, controlling shape and measuring performance. The analyses, studies and conceptual design work currently in progress plus planned ground and shuttle-based tests will reduce the risk and are necessary precursors to this TDM. By comparison the other items are of relatively low risk. For Approach 2, the possible delay or inadequacy of the antenna which is being used by the TDM is an added risk.

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CRITICAL ITEM AND RISK ASSESSMENT
TDM NO. 3

TRW

NO.	ITEM	RISK			COMMENT
		COST	PERF	SCHED	
1	COMMON – BOTH APPROACHES				
2	ANTENNA TECHNOLOGY	●	●	●	IMPACTS DESIGN, MANUFACTURING COST, SCHEDULE
3	ADAPTIVE CONTROL TECHNOLOGY	●	●	●	KEY DYNAMIC CONTROL AND SHAPING TECHNOLOGY FAILS TO MATURE
4	MEASUREMENT SYSTEM TECHNOLOGY	●	●	●	KEY CAPABILITY TO MEASURE SHAPE AND RF PATTERN LAGS
5	SCHEDULE TO LAUNCH	◑		◑	SCHEDULE MISSED DUE TO CUMULATIVE EFFECTS OF ITEMS SUCH AS 2, 3, 4 ABOVE
6	STS DELAY	○		○	
7	TIME TO PERFORM ON-ORBIT PROGRAM	◑		◑	
8	SPACE STATION AVAILABILITY/ CAPABILITY	○		◑	
9	TMS MODS	○		○	IMPACTS RF MEASUREMENT – NOT TOTAL PROGRAM
10	APPROACH NO. 2				
11	AVAILABILITY OF ANTENNA	●		●	ANTENNA USED BY TDM NOT AVAILABLE FROM ANOTHER PROGRAM

○ LOW RISK ◑ MODERATE RISK ● HIGH RISK

EARLY SPACE STATION VS. STS TRADEOFF - TDM 3

The key advantages of the space station over the STS for this TDM are accommodation of the large size and the advantage of time - particularly non-contigious blocks of time. The TDM has several phases including 1) deployment, 2) in-orbit construction e.g., stiffening, 3) initial shaping and measuring, 4) dynamic control testing and 5) pattern measurement. Each of the phases - particularly shaping, dynamic control and pattern measurement will be iterative. Time will be required between tests to evaluate data and plan further tests. The various technologies involved in this TDM are common to any large, flexible space-based structure and it is therefore appropriate that the space station become, as a result of this TDM, a facility for testing and verification of other large antenna and large structures in general.

EARLY SPACE STATION VS STS TRADEOFF
TDM NO. 3

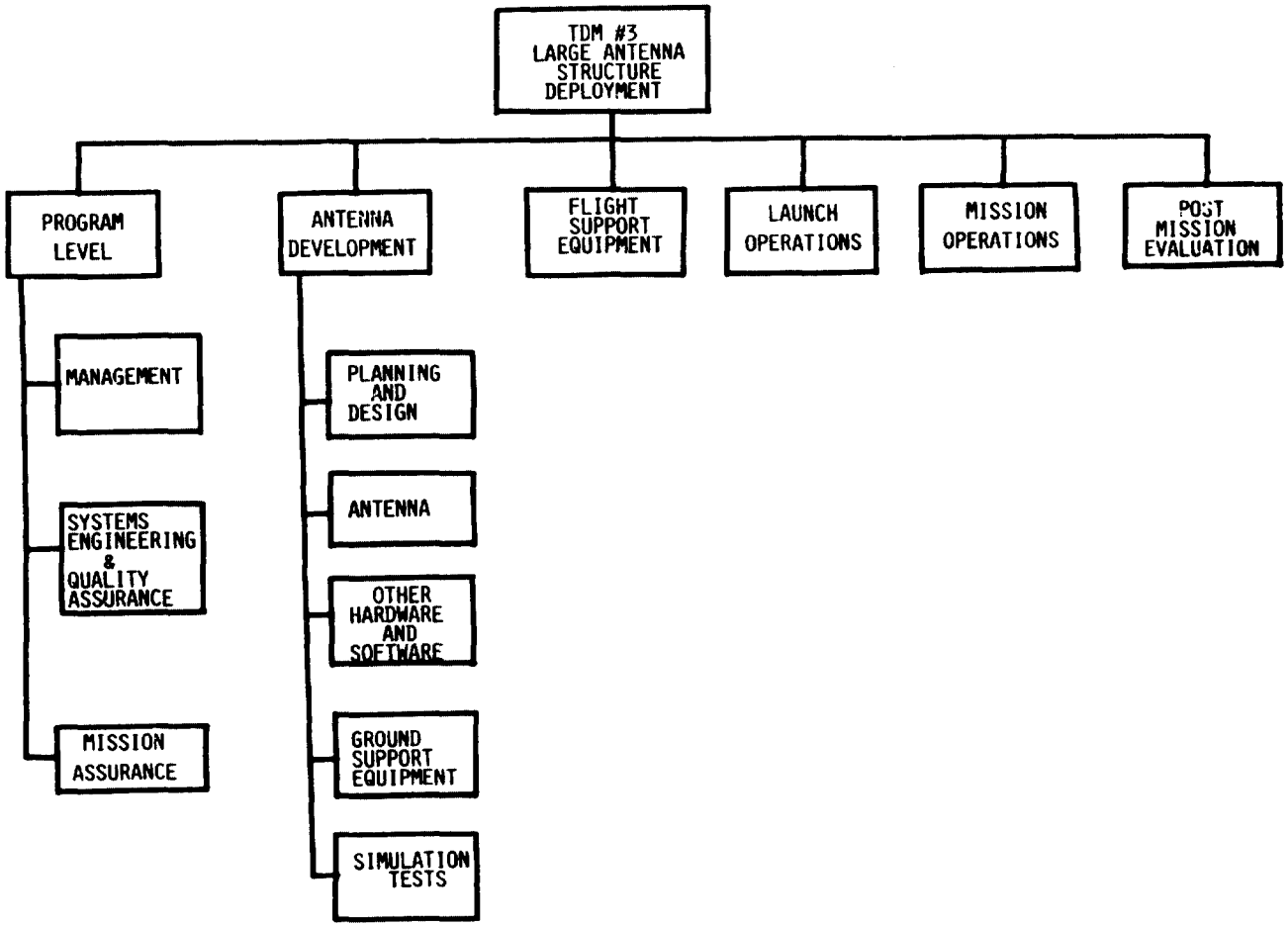
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NO.	DESCRIPTION	ADVANTAGE		COMMENT
		STS	SS	
1.	TIME ON-ORBIT		√	STS IS NOT TIED UP IN-ORBIT FOR EXPERIMENTS; SS IS AVAILABLE FOR EXTENDED TIMES
2.	AVAILABILITY OF UNIQUE SUPPORT EQUIPMENT		√	EQUIPMENT CARRIED TO ORBIT ONCE WITH MOST EFFICIENT MANIFESTING OF STS
3.	AVAILABILITY OF GENERAL PURPOSE SUPPORT EQUIPMENT		√	RMS, TMS, CONSTRUCTION PLATFORMS, ETC., AVAILABLE ON-ORBIT. TRANSPORT BACK AND FORTH VIA STS NOT REQUIRED
4.	IN-PLACE CAPABILITY		√	UPON COMPLETION OF TESTS AN IN-PLACE CAPABILITY WILL EXIST TO SUPPORT FUTURE ANTENNA/STRUCTURE ALIGNMENT, MEASUREMENT OF PERFORMANCE OF LARGE, FLEXIBLE STRUCTURES, RF PATTERN MEASUREMENT, ETC
5.	RETURN EXPERIMENT TO GROUND	√		QUICKEST TURN-AROUND OF ENTIRE EXPERIMENT FOR MAJOR REWORK ON THE GROUND IS WITH AN STS-BASED TEST
6.	ANTENNA SIZE		√	ANTENNA CAN BE LARGER ON SS
7.	AVAILABILITY OF SS	√		

WORK BREAKDOWN STRUCTURE - TDM #3

The work breakdown structure for TDM #3 varies from the generic version due to the potential for major development of a large 60 meter antenna. Due to this potential for a major cost item, the antenna development is provided explicit identity in the WBS. The TDM planning and design is included in the antenna development portion of the WBS. Both Approaches 1 and 2 to the costing of this TDM will utilize this WBS.

WORK BREAKDOWN STRUCTURE - TDM #3



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COST SUMMARY - TDM #3

TDM #3 also has two approaches for cost. Approach #1 assumes that a 60 meter antenna will be developed specifically for the TDM. Approach #2 assumes that the 60 meter antenna is available from a mission where the 60 meter antenna is necessary to accomplish a mission and the TDM would represent an additional task that would be added to the mission.

The total cost for Approach #1 is 123.8 million dollars. Of this total, over 70% is represented by the TDM development cost, including development of the antenna. The total for this TDM development is 87 million dollars. The total cost for Approach #2, on the other hand, is only 19.8 million dollars of which the TDM development and antenna cost represents only 43% of the total cost. The flight support equipment cost was also significantly reduced from 14.7 million dollars to 2.9 million dollars by taking Approach #2. Similarly the launch operations cost have been estimated to be reduced from 1.4 million to 0.9 million dollars for Approach #2.

COST SUMMARY - TDM #3

MILLIONS OF 1984 DOLLARS

WBS ITEM	APPROACH #1	APPROACH #2
PROGRAM LEVEL	18.4	5.4
ANTENNA DEVELOPMENT	87.0	8.5
FLIGHT SUPPORT EQUIPMENT	14.7	2.9
LAUNCH OPS	0.9	.2
MISSION OPS	2.4	2.4
POST FLIGHT EVALUATION	0.4	0.4
	123.8	19.8

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- SUBTASKS AND SUBTASK TOPICS COVERED FOR EACH TDM:

TASK 3.1 PLANS AND SCHEDULES

- SCHEDULE
- CRITICAL ITEM ASSESSMENT
- RISK ASSESSMENT

TASK 3.2 COST ANALYSIS

- EARLY SPACE STATION VS. SHUTTLE TRADEOFF
- COST ANALYSIS

- TDM ADDRESSED ON THE FOLLOWING PAGES

TDM 1 BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY

TDM 2 ON-ORBIT SPACECRAFT ASSEMBLY, TEST AND LAUNCH

TDM 3 LARGE ANTENNA STRUCTURE DEPLOYMENT

TDM 4 SERVICE/REFURBISH SATELLITE (GRO)

TDM 5 SERVICING OF FREE-FLYING MATERIALS PROCESSING PLATFORM

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TDM-PECULIAR COSTING GROUND RULES

TDM #4 GRO REFURBISHMENT & REPAIR

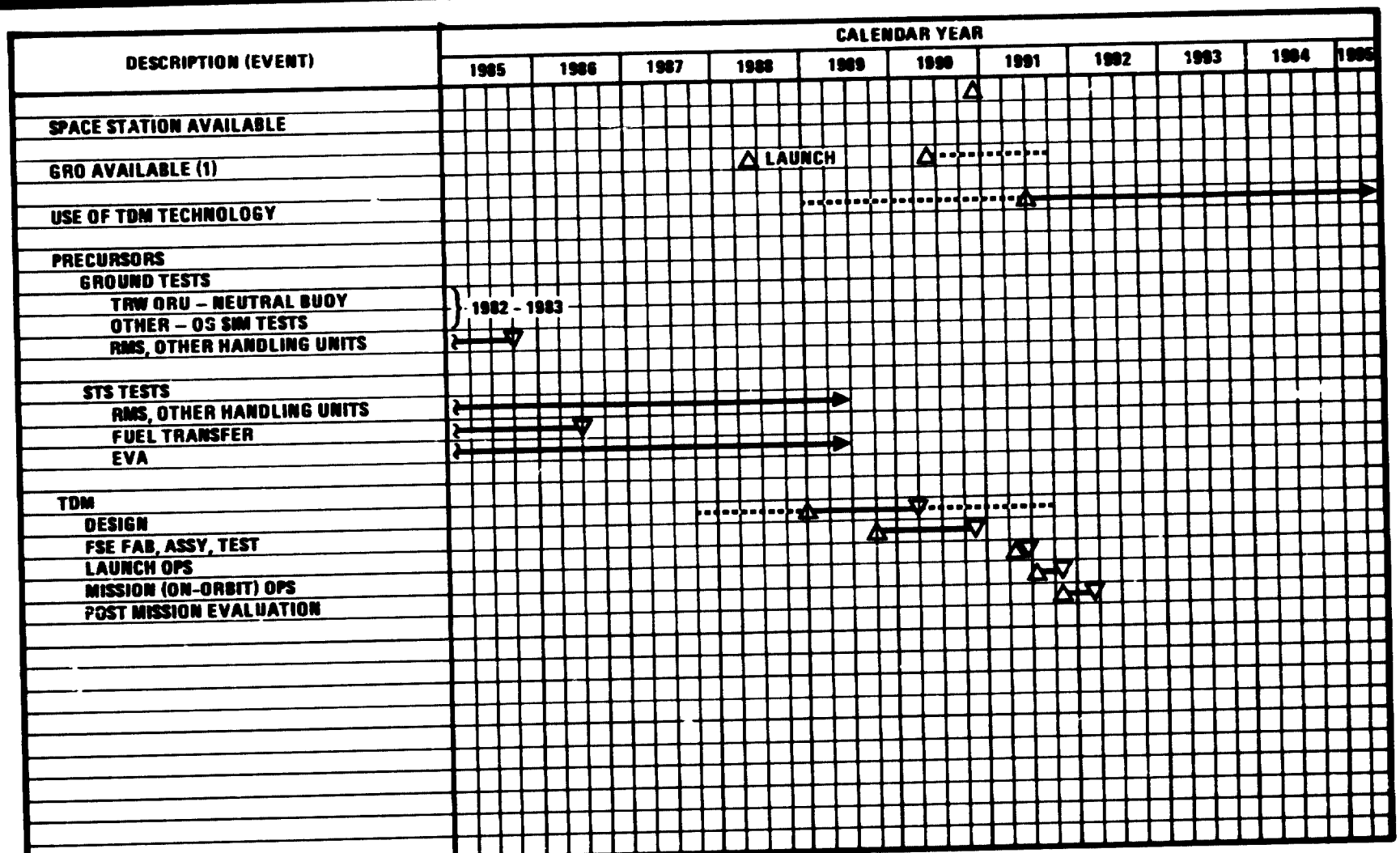
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- END OF GRO MISSION COINCIDES WITH EARLY SPACE STATION TIME FRAME.
- THE GRO SATELLITE IS RETAINED IN ORBIT AND IS AVAILABLE FOR THIS TDM.
- THIS TDM USES GRO AS-IS, I.E., THE TDM DOES NOT IMPOSE COST, SCHEDULE OR PERFORMANCE CONSTRAINTS ON GRO.
- TMS IS AVAILABLE PREFERABLY WITH CAPABILITY TO CAPTURE AND RETRIEVE GRO.
- GROUND STATION CAPABILITY FOR GRO IS MAINTAINED UNTIL TDM IS COMPLETED. (THIS COST IS NOT CONSIDERED A COST TO THE TDM.)
- PROPELLANT LOADING CAPABILITY FOR MONOPROPELLANT HYDRAZINE EXISTS THE SPACE STATION AND IS AVAILABLE AT NO COST TO THE TDM.

SCHEDULE - TDM 4

The most significant item in this schedule is the difference shown between the GRO availability and the space station availability. GRO is currently scheduled to launch in May 1988 and has a mission duration of two years. Possible delays in GRO and desire to continue gathering science data for more than two years may keep GRO on orbit beyond May 1990 and close the gap. However, delays in the space station will widen the gap. Further speculation is not warranted. The total time to prepare for the TDM is relatively short - on the order of 30 months - where the initial phase is a relatively low level planning phase.

SCHEDULE - TDM NO. 4



(1) TDM REQUIRES GRO TO BE MAINTAINED IN-ORBIT UNTIL SPACE STATION IS AVAILABLE

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CRITICAL ITEM AND RISK ASSESSMENT - TDM 4

The most critical item causing the greatest risk is the in compatibility in the availability of GRO and the space station. (See discussion of the preceeding schedule chart). All other critical/risks are lower by comparison.

Mission & Systems Engineering
TRW Space & Technology Group

CRITICAL ITEM AND RISK ASSESSMENT
TDM NO. 4

TRW

NO.	ITEM	RISK			COMMENT
		COST	PERF	SCHED	
1	GRO AVAILABILITY	◑	–	◑	SCHEDULES FOR GRO AND SS BECOME TOTALLY INCOMPATIBLE
2	STS DELAY	○	–	○	
3	TIME TO PERFORM TDM	◑	–	◑	TIME UNDERESTIMATED
4	SS AVAILABILITY/CAPABILITY	○	–	◑	NOT AVAILABLE AS DRIVEN BY GRO ON-ORBIT LIFE
5	TDM DESIGN/FSE	◑	○	◑	
6	TMS CAPABILITY	–	◑	–	TDM ASSUMES TMS CAPABLE OF REMOTE CAPTURE OF GRO WITHOUT USING STANDARD GRAPPLE (1)

○ LOW RISK ◑ MODERATE RISK ● HIGH RISK

(1) OTHER SCENARIOS POSSIBLE INCLUDING RENDEZVOUS WITHOUT TMS

EARLY SPACE STATION VS. STS TRADEOFF TDM 4

The current GRO baseline designs for retrieval and servicing by the STS. That baseline concept will remain because the space station is not available during the planned GRO mission. For that reason it would appear more cost effective to retrieve and service GRO using STS only. However, GRO is an ideal candidate for very early verification of servicing at the space station. GRO's mission is completed and it is available essentially free to be used for a variety of servicing experiments.

EARLY SPACE STATION VS STS TRADEOFF
TDM NO. 4

NO.	DESCRIPTION	ADVANTAGE		COMMENT
		STS	SS	
1.	TIME ON-ORBIT		✓	STS NOT TIED UP CONDUCTING ON-ORBIT EXPERIMENTS
2.	STS TRANSPORTATION COSTS		✓	IF STS IS USED FOR THIS TDM AT LEAST SOME STS PAY-LOAD CAPABILITY WOULD BE LOST AND THEREFORE BECOME CHARGEABLE TO THE TDM (SEE ITEMS 3 AND 4)
3.	AVAILABILITY OF UNIQUE SUPPORT EQUIPMENT		✓	CARRIED TO ORBIT ONCE AND LEFT IN PLACE OR STORED ON SS FOR FUTURE USE
4.	AVAILABILITY OF GENERAL-PURPOSE SUPPORT EQUIPMENT		✓	RMS, CONSTRUCTION PLATFORMS, ETC., AVAILABLE ON-ORBIT – NOT REQUIRED TO BE TRANSPORTED TO AND FROM ORBIT FOR EACH USE
5.	GRO END OF LIFE	✓		GRO MAY REQUIRE DE-ORBITING BEFORE SPACE STATION IS READY

COST SUMMARY - TDM #4

The cost for TDM #4 is associated with planning and developing hardware and equipment for the repair and refurbishment of the Gamma Ray Observatory (GRO) satellite. The total cost for this TDM is estimated to be 5.5 million dollars. Since most of the hardware needed for the TDM already exists in the GRO satellite, including spares, the total cost for this mission is relatively nominal. Over 60% of the total 5.5 million dollars in cost is represented by the TDM development cost.

COST SUMMARY - TDM #4

MILLIONS OF 1984 DOLLARS

WBS ITEM	COSTS
PROGRAM LEVEL	1.1
TDM DEVELOPMENT	2.8
FLIGHT SUPPORT EQUIPMENT	0.5
LAUNCH OPERATIONS	0.4
MISSION OPERATIONS	0.5
POST MISSION EVALUATION	0.2
SUB-TOTAL	5.5

TASK 3.1 AND TASK 3.2

- SUBTASKS AND SUBTASK TOPICS COVERED FOR EACH TDM:

TASK 3.1 PLANS AND SCHEDULES

- SCHEDULE
- CRITICAL ITEM ASSESSMENT
- RISK ASSESSMENT

TASK 3.2 COST ANALYSIS

- EARLY SPACE STATION VS. SHUTTLE TRADEOFF
- TDM COST ANALYSIS

- TDM ADDRESSED ON THE FOLLOWING PAGES

TDM 1 BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY

TDM 2 ON-ORBIT SPACECRAFT ASSEMBLY, TEST AND LAUNCH

TDM 3 LARGE ANTENNA STRUCTURE DEPLOYMENT

TDM 4 SERVICE/REFURBISH SATELLITE (GRO)

TDM 5 SERVICING OF FREE-FLYING MATERIALS PROCESSING PLATFORM

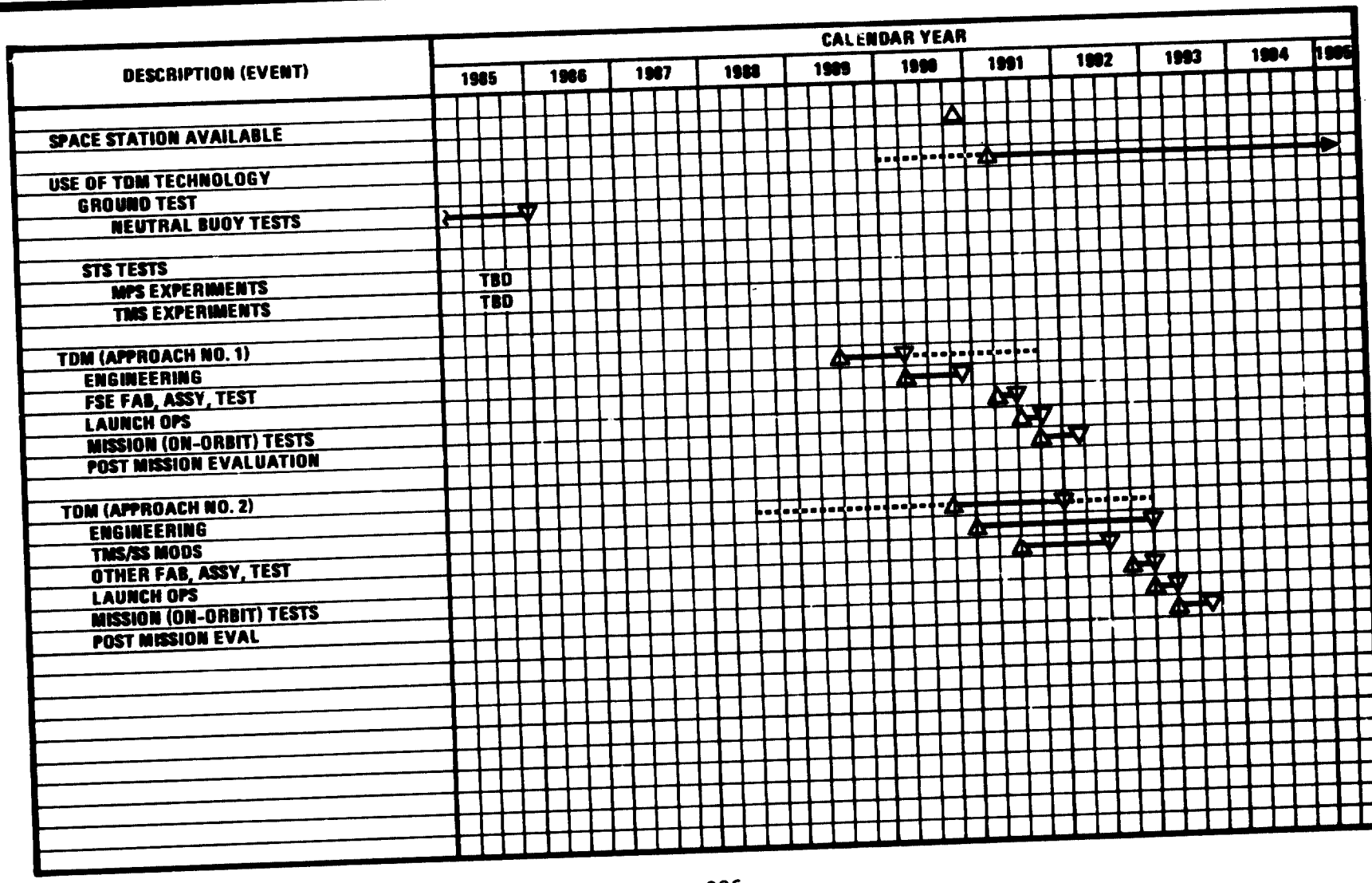
TDM-PECULIAR COSTING GROUND RULES

TDM #5 SERVICING OF AUTOMATED, FREE FLYING MATERIALS PROCESSING PLATFORMS

- A CO-ORBITING PLATFORM IS AVAILABLE WITH REAL OR SIMULATED MATERIALS PROCESSING CAPABILITY.
- TMS IS AVAILABLE FROM THE SPACE STATION FOR THE TDM AT NO COST TO TDM.
- TWO APPROACHES WERE TAKEN RELATIVE TO THE TMS ROBOTICS:
    1. ADVANCED ROBOTICS IS AVAILABLE ON THE TMS TO PERFORM MATERIALS HARVESTING FROM THE PLATFORMS.
    2. ADVANCED ROBOTICS WOULD NEED TO BE DEVELOPED FOR THE TMS TO PERFORM TDM.
- PROPELLANT LOADING CAPABILITY IS AVAILABLE FROM THE SPACE STATION.

Two approaches for this TDM are scheduled. Approach 1 primarily involves planning and interfacing with the materials processing program, TMS operation and space station to coordinate the TDM design and data gathering process. Allowance is made for design of a small amount of TDM-unique equipment or software to be placed on the space station. Approach 2 involves additional hardware/software on the space station and some additional growth in robotic-type attachments on the TMS so that this TDM can experiment with more advanced, automated harvesting, raw material replenishment and handling on the space station.

SCHEDULE - TDM NO. 5



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The TDM is dependent upon both the availability of in-place technology and equipment designed to use that technology. These are the two most critical items of greatest risk.

CRITICAL ITEM AND RISK ASSESSMENT
TDM NO. 5

NO.	ITEM	RISK			COMMENT
		COST	PERF	SCHED	
1	MATERIALS PROCESSING PLATFORM AVAILABILITY	◑	–	●	PLATFORM WITH REAL OR SIMULATED PROCESSING REQUIRED
2	STS DELAY	○	–	○	
3	TIME TO PERFORM TDM	◑	–	◑	TIME UNDERESTIMATED
4	SS AVAILABILITY/CAPABILITY	○	–	◑	SS SCHEDULE DELAYED
5	TDM DESIGN/FSE	◑	○	◑	
6	TMS AVAILABILITY/CAPABILITY	○	◑	◑	
7	AUTOMATED PROCESSING FACILITY TECHNOLOGY	◑	◑	◑	KEY AUTOMATED TECHNOLOGY DEVELOPMENT IS DELAYED

○ LOW RISK ◑ MODERATE RISK ● HIGH RISK

As the chart shows, the early space station provides advantages for this TDM compared to the STS. Conduct of the test, including iterations, are not constrained by orbiter stay time. Non-contiguous test periods are possible without the constraint of re-flights. If the space station is to be used for frequent, routine service of co-orbiting platforms, then the use of the early space station to verify this capability and implace it on the space station is important. Test of higher degrees of servicing automation geared toward production in space are also highly suited to the space station.

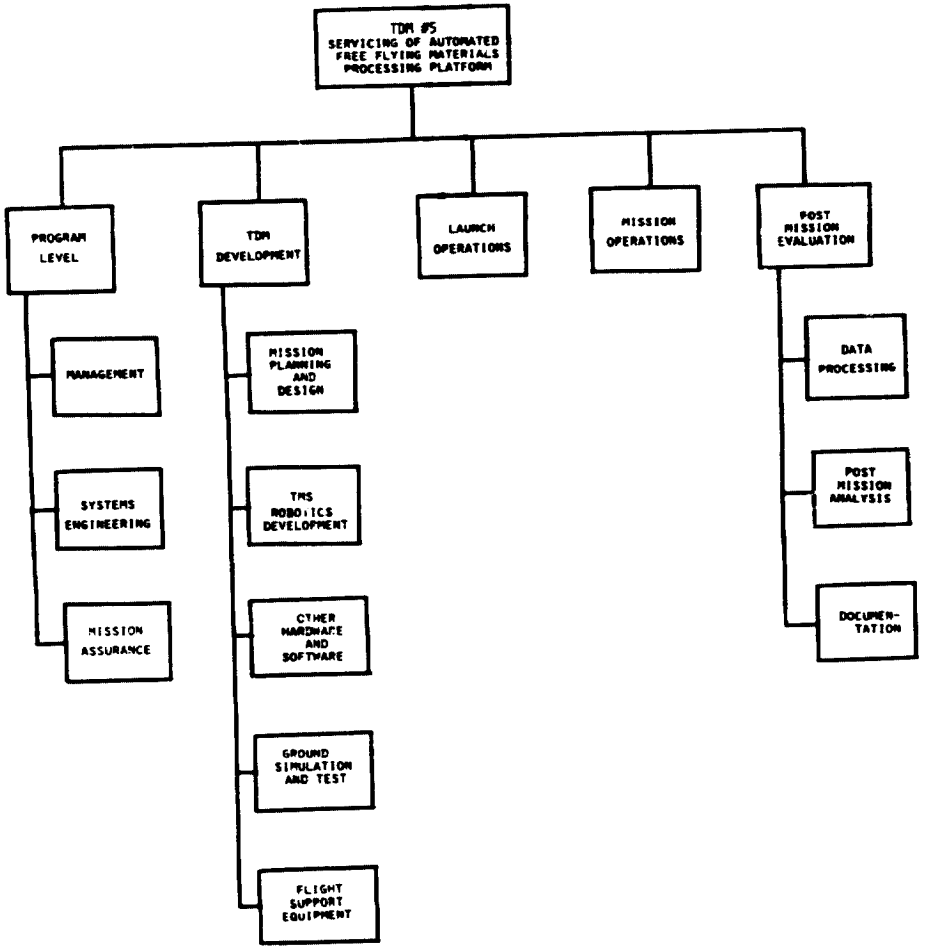
EARLY SPACE STATION VS STS TRADEOFF
TDM NO. 5

NO.	DESCRIPTION	ADVANTAGE		COMMENT
		STS	SS	
1.	TIME IN ORBIT		✓	CONDUCT OF TEST IS NOT CONSTRAINED TO STS ON-ORBIT TIME
2.	STS TRANSPORTATION		✓	IF STS IS USED FOR THIS TDM SOME STS CARGO WOULD BE CHARGEABLE TO THIS TDM (SEE ITEMS 3 AND 4)
3.	AVAILABILITY OF UNIQUE SUPPORT EQUIPMENT		✓	CARRIED TO SPACE ONCE, EQUIPMENT IS LEFT IN PLACE FOR FUTURE USE
4.	AVAILABILITY OF GENERAL SUPPORT EQUIPMENT		✓	TMS AND OTHER SUPPORT EQUIPMENT AVAILABLE ON-ORBIT. TRANSPORT TO/FROM ORBIT FOR EACH USE IS NOT REQUIRED
5.	TIMEFRAME	✓		USE OF STS IS MORE ADVANTAGEOUS IF EARLY (1985 - 1990) VALIDATION OF AUTOMATED MATERIALS PROCESSING IS DESIRED

WORK BREAKDOWN STRUCTURE - TDM #5

The WBS for this TDM differs slightly from the standard version in order to emphasize the potential for significant costs in the development of advanced robotics for the Teleoperator Maneuvering System (TMS). Two approaches were taken in costing this TDM. Approach #1 assumes that all space station and TMS capabilities to support this TDM exist at the time the TDM is to be performed. Approach #2 assumes that the evolution of the TMS and the space station have not reached that level of capability that permits TDM #5 to be accomplished.

WORK BREAKDOWN STRUCTURE - TDM #5



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COST SUMMARY - TDM #5

The cost estimates for TDM #5 also consider two approaches. Approach #1 assumes that all of the space station and TMS capabilities necessary to complete this TDM are available for the TDM. Approach #2 consider the possibility that the space station capabilities and the TMS robotics capabilities are not yet advanced to the stage where it can handle this TDM. For example, special environment control storage facilities for the harvested material from the Materials Processing Platform (MPP) may be required or the robotics on the TMS have not been advanced to the stage where it is capable of harvesting material from the MPP. In the event these are not available, development of these items are required.

The total cost for Approach #1 is 5.7 million dollars, where Approach #1 assumes that all of the capabilities necessary to complete the TDM are available. Approach #2 requires an estimated 14.1 million dollars to complete the mission where more than 60% of this total cost, 8.5 million dollars, is in TDM development. Of this total for TDM development, 4.0 million is estimated for space station support items and TMS robotics enhancement.

COST SUMMARY - TDM #5

MISSIONS OF 1984 DOLLARS

WBS ITEM	APPROACH #1	APPROACH #2
PROGRAM LEVEL	1.3	2.2
TDM DEVELOPMENT	3.0	8.5
FLIGHT SUPPORT EQUIPMENT	0.5	1.6
LAUNCH OPERATIONS	0.2	0.9
MISSION OPERATIONS	0.5	0.6
POST FLIGHT	0.2	0.2
TOTAL	5.7	14.0

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TASK 3 INTRODUCTION AND SUMMARY

TASK 3.1 PLANS AND SCHEDULES

TASK 3.2 COST ANALYSIS

TASK 3.3 ENVIRONMENTAL ANALYSIS

The Environmental Analysis report has been completed and delivered. Since much detailing of the five defined TDMs is yet to be done, it cannot be finally stated that no impact will exist. However, in treating the three categories as generic TDMs and considering the five TDMs at their present level of design, no significant environmental impact appears to exist.

ENVIRONMENTAL ANALYSIS - SUMMARY REPORT

- ENVIRONMENTAL ANALYSIS REPORT COMPLETED AND DELIVERED 7 JANUARY 1983 (DR-5)
- TREATED THE THREE CATEGORIES GENERICALLY
- PATTERNED AFTER SIMILAR ENVIRONMENTAL ASSESSMENT REPORTS
- FINDING IS THAT IDMS CURRENTLY BEING CONSIDERED WILL NOT JEOPARDIZE THE ENVIRONMENT

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Conclusions

CONCLUSIONS

In addition to the always applicable conclusion in an early definition study of this type that -- "more study work should be performed" -- the opposite page chart draws attention to four specific conclusions from this effort. They pertain to technical feasibility, user benefits, early space station's role, and start of critical technology.

In evolving a technology base for future satellite servicing from the space station, many issues and questions pervade the various disciplinary considerations. The degree of autonomy desired and man-machine interface questions are typical examples. In addition, the initial and life-cycle costs and evolutionary growth guidelines are clearly the dominant drivers in planning a technology program responsive to satellite servicing/space station needs. To better describe the technology goals and to facilitate communications across disciplinary lines, this study has identified an initial list of primary TRW TDMs and derived their requirements.

The benefits of having a space station are: (1) the capability it will afford to conduct servicing, repair, and upgrading of satellites or the space station itself on orbit, (2) the assembly and checkout for flight of spacecraft whose final configuration exceeds the single flight STS payload-to-orbit capability, and (3) the release of the shuttle from on-orbit, long-duration operational tasks to allow it to be more efficiently used as a space transportation vehicle.

Satellite servicing on orbit provides benefits that can be evaluated. It is cost effective because once the capabilities are in place, they can be applied to the entire spectrum of commercial, scientific, and government satellites. Among these benefits are:

1. Extended satellite lifetimes
2. Low satellite costs
3. Improved satellite performance
4. Reusable satellites for mission flexibility
5. Optimized science through instrument changeout
6. Higher satellite reliability

The study-generated TDMs serve as foci for technological innovation to enhance or enable a space station capability consistent with NASA's guidelines. While the TDMs foster interdisciplinary considerations, it must be recognized that the TDMs themselves are highly interdependent with strong synergism.

It is uncertain at this time if budget reality will allow near-term implementation of efforts directed at all of the technology goals identified in the study to date. However, it is reasonable to project that an extremely challenging technology development study phase has been initiated by MSFC which addresses the highest priority tasks and affords increased U.S. capability for satellite operations.

CONCLUSIONS

1. ON-ORBIT SATELLITE SERVICING IS TECHNICALLY FEASIBLE

2. ON-ORBIT SATELLITE SERVICING WILL SUPPORT A WIDE RANGE OF NASA, DoD, AND COMMERICAL MISSIONS. THE BROAD NATURE OF THIS SUPPORT WILL PORTEND OPERATIONAL, AND MAYBE ECONOMICAL, BENEFITS TO THE USERS

3. THE EARLY SPACE STATION CAN AND MUST PLAY A VITAL ROLE IN DEVELOPING A NATIONAL SATELLITE SERVICING ON-ORBIT CAPABILITY

4. DEVELOPMENT OF CERTAIN CRITICAL TECHNOLOGY ELEMENTS NEEDED TO PERFORM ON-ORBIT SATELLITE SERVICING SHOULD BE STARTED AT AN EARLY DATE

Appendix A

RESULTS OF TRW INTERNAL TECHNOLOGY REQUIREMENTS SURVEY

As a part of Study Task 1 an internal survey was conducted among TRW spacecraft design specialists for assistance in defining and delineating satellite servicing technology issues. The questions listed below were formulated as a guide for general comments and suggestions by engineers participating in this survey. Participants included:

Robert Benhabib	(Attitude Control and Automation)
Raphael Gluck	(Spacecraft Dynamics)
Tom Hanes	(Commercial Uses of Space Station)
Leroy Herold	(Thermal Control)
Gary Johnson	(Crew Systems)
Tom Johnson	(Propulsion)
Robert Neiswander	(Large Deployable Structures and Control)
Sets Okumura	(Space Station Layout)
Hans Rauschenbach	(Power Subsystem/Solar Arrays)
Ken Rourke	(Space Station Mission Requirements)
Ralph Schilling	(Space Science and Applications)
R. F. Walters	(Space Station Operations)

Questions Regarding On-Orbit Satellite Servicing Technology Needs*

1. Principal refurbishment/replacement/resupply needs in your area of discipline or subsystem technology.
2. What are the failure or wearout mechanisms?
3. How complex is this refurbishment?
4. What is the state of technology as to on-orbit repair feasibility?
5. What kind of new technology is needed, and when will it be available?
6. Have modular replacement concepts been studied. When and by whom?

*Explanatory notes distributed with this questionnaire provided background on our preliminary technology plan and the TDM categories being considered. The importance of time-phased technology evolution was emphasized as a principal issue.

7. Any literature references you can think of?
8. Does this new technology warrant/require demonstration in space? Can this be done on the shuttle orbiter?
9. Does the technology development depend on flying specific missions (so-called Technology Development Missions, TDM)?
10. What do you expect to be man's role in this process (manual tasks, remote control etc.)?
11. What dexterity is required? Can a suited crewman perform the task?
12. Can this task be done off station, that is, "in situ" by a Teleoperator?
13. Why do the refurbishing on the space stations rather than the shuttle?
14. What safety issues do you foresee, if any?
15. How costly do you think this service function will be (large, medium, modest costs)?
16. Can the satellite and subsystem designs be standardized sufficiently in the future to facilitate the servicing operations and implementation?

I. SERVICING OPERATIONS AND DESIGN IMPLICATIONS

The following answers refer to issues in the above questionnaire by number.

Spacecraft subsystem packaging along the lines of the "Multimission Modular Spacecraft" (MMS) is necessary as a basic premise of standardization required for servicing.

1. Probably none of the entirely electronic subsystems or the electronic part of a subsystem needs replacment more than another. However, due to the great strides being made in the increasing speed of calculations (higher clock rate), larger memory and smaller physical size of developing processors, the most likely candidate for the earliest refurbishment is the Communication and Data Handling Subsystem. This would be true for either the palletized systems attached to a space station or a free flyer. The free flyer would require resupply of propellant periodically.

2. Any rotating device will eventually wear out. For example, on those satellites that require reaction wheels for stability replacement may be required; a reaction wheel could be just another attached module. Some disassembly may be necessary to achieve access to the reaction wheel module.

   Solar arrays will gradually deteriorate due to charged particle impingement. This occurs at a faster rate in GEO than it does in LEO. Replacement of an entire array may be required in less than 10 years. Degradation due to thermal cycling, and possibly atomic oxygen effects, will be greater in LEO.

3. Most refurbishment would be by replacement of the subsystem modules which, with MMS type standardization, should not be complex. Each module would be held to the basic structure with 2 captive jack screws. The electrical connections would be of the "rack and panel" or "zero entry" type. This replacement could be accomplished by EVA. The payload could be refurbished by module replacement, if it were so designed, or the entire payload could be replaced. In either case the mechanical interface would be several jack screws, and the electrical interface would be by means of "rack and panel" connectors. Complication due to lack of access to a module must be avoided by appropriate design layout.

4. The technology of modular subsystems already exists. The demonstration of replacement in-orbit will be performed with replacement of the ACS module on the Solar Max (SMM) satellite in 1984.

   In 1985, a limited capability to repair satellites in LEO will exist. A constraint, besides LEO, will be the slow evolution of new satellites which have modular construction i.e., MMS type, and which are capable of rendezvous with the shuttle and have adequate safety provisions.

5. (1) A new suit for EVA that is pressurized to 10 psi so that pure O_2 preconditioning is not required. This should be available by 1990.
(2) A teleoperator (TMS) to perform the capture and retrieval of satellites to the SS. See Vought Corp. report "Teleoperator Maneuvering System etc", May 1982. This device will not be operational until at least 1988.
(3) A manned space station of sufficient mass and attitude control such that a shuttle and/or satellite may be attached with no orbital disturbance. The servicing facility provided by the space station must be capable of performing tests in addition to repair and refurbishment of retrieved satellites. The IOC of this type of SS is 1991.
(4) Probably the most pressing initial need is for satellite refueling. Most LEO satellites run out of propellant and self-destruct (uncontrolled reentry or freeze) before they are technically outdated. Therefore, refueling could extend the life of a satellite until the capability to refurbish the satellite becomes available.

6. The "Multimission Modular Spacecraft" (MMS) has been developed for NASA by McDonnell Douglas and Fairchild. Fairchild also is proposing a spacecraft using the MMS concept to carry numerous types of interchangeable payloads. This spacecraft/payload combination could be assembled on the ground in sections or as a whole, or it could be completely assembled on a space station.

7. See the reference list contained in the Mid Term Briefing NASW-3681, 18 November 1982 by TRW.

8. The biggest advantage to satellite assembly or servicing in space (fueling and/or refurbishment) in a space station as opposed to shuttle is the time constraint. The shuttle has a limited orbital stay time. Also, for a free flyer that weighs more than 65k lb, a space station is necessary for assembly and/or fueling.

9. Any of these technologies can be accomplished and proven in conjunction with projected scientific or applications payload missions. The establishemnt of a space station itself will prove the assembling technology.

10. At the onset of space station construction there will be considerable EVA. This will decrease as more robotics and teleoperators are developed, and when shirt sleeve environment for satellite assembly/servicing is established. Man's role will be to initialize and monitor the automatic and remote processes.

11. On the premise that only MMS type modules will be assembled or replaced in space, the degree of dexterity will not exceed that of a suited crewman. Similarly, the task of fueling/refueling. Any further disassembly would have to take place in a shirt sleeve environment or requires returning the vehicle to earth.

12. If the robotics of the teleoperator is sufficiently refined to handle the modules, there is no reason that module replacement cannot be accomplished in situ.

13. Where the length of time for refurbishment exceeds the orbital stay time of the shuttle, it must take place on the space station. In case of contingency, the space station would probably be more capable of work-around activities i.e., if the replacement module malfunctions, mounting surface is damaged, or more extensive functional tests are required.

14 Any fuel transfer in space is a potentially hazardous situation

Handling and transfer of large objects by EVA crew members can be hazardous, and precautions must be taken to avoid collision by appropriate, timely reduction of momentum. The crewman must be trained to estimate the momentum and the required retarding force or torque.

15. Servicing of a satellite or even the change of the payload will be at a very modest cost by comparison with the launch and risk of a new satellite.
16. As soon as reliable cost figures can be analyzed and compared, the aerospace industry will standardize on subsystem designs that are servicable in space. This has already been started by McDonnell and Fairchild, see Question 6.

II. SPACE STATION ATTRIBUTES AND CAPABILITIES

The following list summarizes space station attributes and capabilities as related to satellite assembly, test and servicing.

1. Satellite Assembly & Test Activity

The space station is required for:

- o Assembly of satellites of gross weight >5.5K pounds for GEO and >44K pounds for LEO.
  (less mechanical handling equipment will be needed to handle a fully assembled satellite)
- o Manual deployment of appendages
  1. Reduces weight of satellite (fewer actuators needed)
  2. Assures complete deployment
  3. Reduces design effort and test requirements of automatic deployment mechanisms. Lower complexity and lower development cost.
- o Storage of propellants.
- o Less thermal-vacuum testing of completed satellites on the ground to verify thermal control system performance.
- o More efficient loading of the shuttle
- o Lower launch load on tanks if transported empty.
- o Housing and operation of checkout equipment.

2. Satellite Servicing Activities

The space station is required for:

- o Repair of satellites by module replacement
- o Satellite refueling
- o Checkout of a repaired or refurbished satellite
- o Change-out of complete payloads
- o Add-on capability to satellites
- o Housing and operation of teleoperator for orbital transfer and remote handling of satellites
- o Housing and operation of OTV for transfer of larger cargo and for larger ΔV requirements (such as LEO-to-GEO transfer).

III. MISSION REQUIREMENTS

The following answers refer to issues in the above questionnaire, by number.

1. For science and applications missions: repair and refurbishment of free flying vehicle, refueling of propulsion systems, replenishment of cooled detector cryogens, changeout of instrument packages, pallet carriers and film packs.

2. Hardware failure - random in nature.

3. This is highly dependent on the type of, and design of the hardware in question.

4. The technology is not so much a problem as the design for maintainability.

5. Refueling; cryogen resupply; modular, replaceable hardware design.

6. Yes, TRW in the space platform design, GSFC/FSEC/MDAC in the MMS spacecraft design, ST design, AXAF design.

7. See numerous reports, particularly on ST, AXAF, and possibly GRO.

8. Many items of technology could be evaluated and validated on the shuttle.

9. This would certainly make sense.

10. Tasks requiring detailed, complex tasks with elements of uncertainty.

11. Necessarily.

12. Unclear if this would be desirable, initially for LEO vehicles. It would probably be necessary for high altitude/GEO missions.

13. Shuttle time on-orbit constraints, need for repair/refurbishment facilities that one would not wish to ship to space for every flight.

14. The usual.

15. Hopefully modest so that it would be economical.

IV. SERVICING TECHNOLOGY ISSUES IN SPACE SCIENCE SATELLITES

NASA Astronomy/Astrophysics satellites currently fit in at least four categories with respect to on-orbit payload servicing:

1. Satellites currently existing or in development for limited-term missions (less than five years) planned to terminate with STS retrieval/return to earth or destructive re-entry. Examples are GRO and SMM (actually a solar physics mission but a good example of this class). No explicit capability for servicing or replacement of scientific instruments is provided during satellite development and in fact no investment is made to insure that the design does not limit or prevent on-orbit access to the instruments. The SMM may be a good demonstration of the ability to service payloads on this class of mission with no prior provision to do so. NASA hopes to replace on-orbit the failed coronagraph electronics box buried within the SMM payload compartment.

2. Observatories currently in development or planned for long-term, facility-class missions (fifteen years on-orbit). Examples are ST and AXAF.* These satellites are designed with modular, standardized payload interfaces that allow for simple on-orbit replacement of individual scientific instruments, including provisions for proper optical alignment of the instrument with the observatory.

3. Facility-class observatories in development or planned for initial use as STS attached payloads with later modification for free-flyers. Examples are SOT and SIRTF.* The scientific instruments for these observatories will be designed to take advantage of man's presence and will be readily interchangeable. In addition, conversion of SIRTF to a free-flyer will include provision for on-orbit cryogenic cooling replenishment (perhaps on six-month intervals).

4. Planned facility class observatories requiring on-orbit deployment or assembly. The LDR (large deployable reflector) is representative of this class. These observatories will require extensive on-orbit manned capability for initial launch and occasional changeout/servicing of scientific instruments.

V. STRUCTURE AND LAYOUT TECHNOLOGY ISSUES

The following answers refer to issues in the above questionnaire, by number.

1. Relating my experience from the Space Platform Study, our servicing and refurbishment concepts were resupply for attitude control propellant, service replaceable ORU's, replace solar array assemblies, thermal radiator, paylaod berthing adapters and STS berthing adapter.

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* SOT - Solar-Optical Telescope
SIRTF - Space IR Telescope Facility
AXAF - Advanced X-Ray Astronomy Facility

2. Failure and wearout will most likely occur in units requiring continuous duty cycles, e.g., the solar array. These wearout mechanisms involve motors, switches, encoders and bearings. Other mechanical components such as gears are reliable enough that damage due to gear binding are highly unlikely to occur.

3. The complexity of replacing the aforementioned units ties directly to their physical interfaces, e.g., how many electrical and data signals are required, aer fluid interfaces involved, does the interface have to sustain large structural loads? These factors must generally be considered, especially for costing purposes. Mechanical joint designs follow everyday common practice and EVA crewman back-up does not pose any serious complications.

4. On-orbit repair is certainly the path that all long orbit life spacecraft and space stations will require. There are several programs (MMS, Space Telescope) that have incorporated on-orbit serviceability into their designs and are presently undergoins extensive zero-g simulated testing. Yes, I believe it is very feasible.

5. New technology needed for servicing spacecraft and space stations will be servicing at the subsystem level or at the component level. As we enter into the space station era; haveing designed and to be afforded sufficient packaging volume, subsystems and components should be designed to be serviced on-orbit and never brought back.

6. and 7.

- o "In-Space Servicing of a DSP satellite" SAMSO TR 74-168 Vol. III 16439-6637-RU-00 By TRW.

- o "Servicing Satellites from the Space Shuttle" Grumman Aerospace Horizons Vol. 18, No 1, 1982

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- o "Space Platform Study" TRW

- o "Satellite Services Systems Analysis Study" LMSC-D792242, Feb. 1981, Lockheed

8. Yes, in-space demonstration is warranted

9. I would say yes where development is towards GEO orbits. You would centainly try to demonstrate its capability on a low orbit base.

10. Man's role to remove, replace and service units will certainly simplify, and reduce the cost of designing components to be serviced remotely. Some equipment may dictate a hybrid approach as a manned remotely controlled robot.

11. A suited crewman can perform any task given the proper working space and tools.

12. Yes, if properly designed for teleoperator.

13. Certain operations may require more time to complete within the shuttle's on orbit stay time. These operations are primary objectives of a space station.

14. Many. Every decipline involves safety issues, e.g., on-orbit refueling, replacing high-voltage electrical power boxes, man's EVA activities, in general.

16. Yes. In the example of our Space Platform design, standardized berthing adapters are used. If all replaceable subsystems were attached with it, all units would have a common interface. Our berthing adapter has standardized fluid, electrical and data interfaces.

VI. ATTITUDE CONTROL AND AUTOMATION

The following answers refer to technology issues in the above questionnaire by number.

1. Gyros, reaction wheels, thruster propellant, film, ECM black boxes, distributed sensing transmitters, distributed electro-mechanical actuators, truss element dampers, viscoelastic truss element replacements, solar arrays and antennas.

2. Examples are friction, consumables depletion, laser diode life, high voltage leaks, outgassing, micro-meteor and radiation damage, epoxy degradation in piezoelectric stacks.

3. Complexity ranges from low (recage) to high (sensor realignment and reaction wheels).

5. The most difficult servicing tasks include uncaging, replaceing and recage; eliminating power shorts to distributed control system components; and sensor alignment.

8. Examples that warrant demonstration in space are multi-body ACS, human interaction with precision control of flexible structures and appendages. Some may be demonstrated on shuttle. But some full-size objects (large structure) may not fit on the orbiter.

10. Manual servicing required in precision tasks. Remote possible in cage/uncage operations.

11. Moderate dexterity required in replacing precision parts or parts that must be precisely aligned. Depends on mechanical and electrical design modularity.

12. Some of the above tasks can be done with a teleoperator, but it depends on size.

13. Some refurbishing must be done at an internal workstation (shirt sleeve environment). Not feasible on shuttle orbiter.

14. Safety issues involve multi-body stability with time varying dynamics.

15. Modest to medium costs .

16. Sufficient standardization feasible? Yes. Design for modularity; snap components on and off; provide alignment guides; design for on-board self test and diagnosis of components.

VII. STRUCTURAL DYNAMICS

The following comments were offered.

1. Testing and simulation of very large structures on the ground has severe limitations. Often cannot model analytically with assured fidelity. Tests in 1g environment not feasible since structure not self supporting.

2. Simulation capability expected to improve by orders of magnitude. (Software and hardware)
   - custom - architectural processing system
   - new mathematical model methodology: computer derives equations, modifies these if desired, eliminates superfluous terms.
   - Digital processors under development that promise 170:1 improvement over main-frame computer.

3. Large structure handling by remote manipulator (RMS): past simulations cumbersome and of doubtful validity. Expect to solve such problems by above new simulation methodology.

4. Other issues to be addressed by new modeling techniques:
   - Tethered system dynamics
   - Dynamics of handling large structure modules in structural assembly
   - Modeling of large antenna structure deformation and control techniques

Overall, an interdisciplinary view is needed in addressing these issues and developing the technology. (Above questionnaire not relevant in this connection).

VIII. THERMAL CONTROL

1. Principal refurbishment/replacement/resupply needs:
   a. Replenish or resupply (liquid or solid) cryogen for cooling detectors, cryogenic computers, etc.
   b. Refurbish or replace low temperature (100°K) passive thermal radiators (currently used on Thematic Mapper)
   c. Clean or refurbish mirrors or other optical surfaces used for space telescopes, laser communication, etc.
   d. Fluid loop system: Replace radiator assembly (if it develops a leak) and replenish coolants.

2. On-orbit servicing feasibility

   For on-orbit servicing to be feasible, the satellite must be designed with this in mind. For example, the cryogen tanks could be designed to be removed and replaced.

3. Issues of crew involvement for effective servicing
   - o Past experience illustrates importance of man's role in servicing: e.g., instellation of sun-shade on Skylab to replace torn-off thermal blanket. Also, crew-assisted deployment of solar array on same mission.
   - o Manned repair service would have been required in failures such as: thermal blanket damage that occured on a early DSC II launch (antenna cover); on 1982 STS missions: Kapton insulation erosion; thermal protection tile loss; on Landsat D: obstruction of antenna boom deployment by loose thermal blanket (subsequently self-corrected)
   - o Deployment of large thermal radiator panel on space platform and space station facilitated by crew assistence.
   - o Replacement of battery pack incl. all electronics and control components as ORU on space platform

IX. PROPULSION

The following answers refer to technology issues in the above questionnaire, by number.

1. Resupply need: Propellants and pressurants.

2. Wearout & failures: Catalyst bed degradation with thru-put for monopropellant systems.

3. Refurbishment would be complex. Trade-offs would probably be toward backup thrusters for both mono and bi-prop systems in addition to existing redundant thrusters.

4. On-orbit repair technology is not currently state of the art. It does not seem that a propulsion system could be designed for easy on-orbit repair or module replacement, without reducing system reliability or without sacrificing design requirements, non-optimum placement of thrusters.

5. The technology for servicing of spacecraft is basically available for mono and bipropellant systems. Moderate technology development effort is required for cryogenic systems.
   - o Russians have transferred both mono and bipropellants, under remote control.
   - o Cryogenic fluid management experiment (CFME) contract has been awarded to TRW
   - o Mono-propellant transfer experiments will be flown on STS 9 to 11 in 1984.

6. & 7. Of the literature on modular replacement, which I have reviewed, propulsion has not been discussed. Other literature refers to earlier propulsion modular studies. See references listed at the end of this Appendix. Also see:

NASA-TM-X-73502 & NASA-TM-X-71683
"Modular Thrust Subsystem Approaches to Solar Electric Propulsion Module Design"

8. In-space demonstration required? Yes.

9. Technology development can be demonstrated as part of another mission (see #5 above).

10. Refueling should be by remote control.

11. See #10.

12. Yes, task can be performed remotely.

13. Volume/mass of fluids required dictate a space depot.

14. See references - also fuel depots should be isolated from the manned space station and could be tethered.

15. Once the depot has been established the service should be of medium cost relative to the alternative.

16. Yes, sufficient standardization can be achieved to facilitate this task.

X. SENSOR TECHNOLOGY FOR LARGE SPACE STRUCTURE CONTROL

General comments include the following:

- o Optical sensors are required for measurement and control of large deployable/erectable precision space structures (mm-wave antennas, IR telescope)
- o 30-m IR telescope requires 5 μm accuracy, one of most challenging applications.
- o Development of laser alignment techniques in process
- o These techniques have been demonstrated in ground-based tests of partial structures. Need further development and test on shuttle or space station-based technology missions.

XI. CREW SYSTEMS TECHNOLOGY REQUIREMENTS

General comments include the following

- o Standardized design needed to facilitate servicing. However, there will always be a mix in standard and custom designs, requiring flexibility.
- o Fault detection, isolation and test, essential to satellite servicing. Need further hardware and software development to achieve best utilization of crew capability.
- o Maintenance/replacement demonstration requires carefully agreed-on operational plan. (Reluctance of satellite project managers to permit crew access).
- o Balanced approach needed in weighing scope of TDM vs. actual mission application.
- o Several candidate servicing approaches to be tried on orbit to learn optimum operational techniques, especially for remote servicing with aid of MMU (Manned Maneuvering Unit).
- o Emphasis on precursor missions is important to proper time-phased technology evolution. Example - Solar Max. Mission (SMM) retrieval by MMU and servicing/replacement of units on shuttle in 1984 will be an important precursor for demonstrating crew capabilities.

- o To improve crew effectiveness in using remote handling (RMS) on the orbiter or space station, development of force measurement (e.g., in berthing task) will be important.
- o Real time in-flight quantitative feedback from crew (as opposed to post-flight interrogation) important in task profile evaluation, performance assessment and finding improved operating modes and defining advanced crew training requirements. (See pages on crew productivity assessment in report text).

XII. SOLAR ARRAY SERVICING

General comments include the following:

- o Modular array design with replaceable panels required for most effective on-orbit servicing.
- o New panels can be spliced in at lap joints, using zippers or plastic snaps to detach/attach modules.
- o Typical life times of 5 years consistent with manned servicing in LEO. In GEO, where such servicing will be much less feasible, 10-year solar array life should be the goal.
- o Annealable GaAs solar cells will make possible on-orbit heat treatment and restoration of arrays after prolonged exposure to particle radiation. ($200^{o}C$ exposure for 1 to 2 hrs will restore 80 to 90 percent of full performance of certain types of GaAs cells). Si cells have not been shown to be annealable.
- o Thermal cycling at LEO currently a major source of S/A wearout, but can be remedied by improved design.

XIII. SPACE STATION SERVICING REQUIREMENTS IN COMMERCIAL USER MISSIONS

Listed below are missions in the "Commercial User" category that require satellite servicing from the space station, including the servicing/tending of free-flying platforms. (Also see TRW Study of Space Station Design Concepts and Architectural Options, 1982-83.)

a. Commercial manufacturing (on free-flying platform to avoid micro-g disturbances in materials processing)
   - o semi conductor materials
   - o vapor growth crystals

- o solution-grown crystals
- o biological materials purification
- o specific glass types

Space station is base for remote periodic resupply and harvesting.

b. Communication Satellites Transshipment
   - o Space station receives satellites (whole or in parts) from orbiter, and tests
   - o Provides warehousing of parts
   - o Assembles and tests the satellites
   - o Attaches satellite to OTV
   - o Fuels the OTV
   - o Performs satellite/OTV launch to GEO

c. Wind/Wave Forecasting
   Mission best performed by mounting the sensors on a separate (free-flying) platform at higher altitude than space station to enlarge scatterometer swath to ~1500 km. Space station deploys free-flyer and services it (replenishment/refurbishment) by periodic retrieval or remotely.

d. Crop condition assessment.
   To be performed on a free-flying platform in order to protect sensitive optical equipment from contaminants near the space station.

e. Renewable Resources Assessment (Seasonal to Annual Inventory).
   The space station will provide support for wide-swath multispectral imaging sensor and its data recording/transmission functions. Alternately, the space stations could deploy a free-flyer to support the sensor.

f. Ocean Color/Temperature Monitoring.
The space station directly supports a visual and IR sensor for marine biological and temperature use. Alternatively, a free-flying platform could be employed to provide greater swath width (as in items c. and d.).

The following addresses some of the questions in the above questionnaire.

3/4. The free-flying platforms will be designed for modular replacement of systems and for replenishment of consumables. Processors and sensors would be whole-unit replaceable.

5. This will require development of orbit-replaceable unit (ORU) technology.

6/7. Past and present studies by TRW.

8/9. Probably requires in-space demonstration, including TDM's specifically designed for the payloads in question and for maintenance/refurbishment techniques.

10/11. Man is "integral" to the process but probably can do it remotely.

13. Frequency of activity and need for frequent, reliable scheduling makes shuttle a very poor choice. Technically the job could be done by shuttle.

14. Safety issues are the same ones as in any EVA tasks.

15. Modest costs.

16. Yes, for commercial use subsystem standardization is mandatory. Everything must aim toward cost reduction or commercial use will not develop.

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REFERENCES

A. MULTIMISSION MODULAR SPACECRAFT (MMS)

1. Anon: Multimission Modular Spacecraft Flight Support System User's Guide. Goddard Space Flight Center, Report 408-2112-0004, March 1980.

2. Multimission Modular Spacecraft PM-1A Propulsion Module Specification, Mar. 1980, GSFC S-700-19/1, 408-2105-002

3. Letter, Wm. Woodruff to F. G. Etheridge, 16 May 1980 "General Arrangement Drawing of Mark II With Current Schematic, Performance Summary and Hardware Selection."

4. Telecom, F. G. Etheridge to L. Mosher of Fairchild, 08 July 1980.

5. NHB 1700.7 "Safety Policy and Requirements For Payloads Using The Space Transportation System (STS)", NASA, May 1979

6. Letter from J. F. Haley, Martin Marietta Aerospace, to F. G. Etheridge, "MMS Mark II Propulsion Module Information," dated 3 July 1980.

7. In-Space Propellant Logistics, Vol. II Technical Report, Contract NAS 8-27692; Space Division, North American Rockwell, Report No. SD72-SA-0053-2, June 23, 1972.

8. Qualification Test Results, LM Interstage Disconnects, Fairchild Stratos-Western, Report No. ER553-5, dated April 23, 1970.

9. Anon: Hazards of Chemical Rockets and Propellants Handbook. CPIA/194, AD 870259, Volume III, Liquid Propellant Handling, Storange and Transportation Propulsion Information Agency, Silver Springs, Maryland, May 1972 (Chapter 9).

10. Jelinek, D.: Thermal Control Analysis of the Flight Support System for the Multimission Modular Spacecraft, ECLSS-590-79-001, Rockwell International, Space Division, Seal Beach, California, 15 August 1979.

11. Anon: Liquid Propellants Handbook, Properties of Hydrazine, Division of Chemical Engineering, Battelle Memorial Institute, Columbus, Ohio 1958.

B. ORBITAL REFUELING OF SPACECRAFT

1. Rpt. #NASA-CR-160334
"Orbital Propellant Handling and Storage Systems Definition Study"
Volume 2: Technical--refueling in space using the STS
General Dynamics/Convair, San Diego, CA

2. Rpt. #NASA-CR-160333
"Orbital Propellant Handling and Storage Systems Definition Study"
Volume 1: Executive Summary--refueling in space using the STS
General Dynamics/Convair, San Diego, CA

3. Rpt. #NASA-CR-93237
"Orbital Refueling and Checkout Study"
Volume 3: Evaluation of Fluid Transfer Modes, Part 2"
Lockheed Missiles and Space Co., Sunnyvale, CA

4. Rpt. #NASA-CR-93233
"Orbital Refueling and Checkout Study"
Volume 2: Study Summary Final Report"
Lockheed Missiles and Space Co., Sunnyvale, CA

5. AIAA Paper 78-942 78/7/00
"Orbital Propellant Handling and Storage Systems"
Heald, D.A., Browns, R.E.

6. Rpt. #NASA-CR-123385
"Orbiting Propellant Depot Safety"
Volume 1: Management Summary Report
Aerospace Corp., El Segundo, CA

7. Rpt. #NASA-CR-123384
"Orbiting Propellant Depot Safety"
Volume 2: Technical Discussion"
Aerospace Corp., El Segundo, CA

8. Rpt. #NASA-CR-165150
"Conceptual Design of an Orbital Propellant Transfer Experiment
Volume 2: Study Results
General Dynamics/Convair, San Diego, CA

9. Rpt. #NASA-CR-159722
"Orbital Refill of Propulsion Vehicle Tankage"
General Dymanics/Convair, San Diego, CA

10. Rpt. #NASA-CR-125909
"Review of Orbital Propellant Transfer Techniques and the Feasibility of a Thermal Bootstrap Propellant Transfer Concept"
Aerospace Corp., El Segundo, CA

11. Rpt. #NASA-CR-123784
"In Space Propellant Logistics"
Volume 1: Executive Summary
North American Rockwell Corp., Downey, CA

12. Rpt. #NASA-CR-123768
"In Space Propellant Logistics"
Volume 4: Project Planning Data
North American Rockwell Corp., Downey, CA

13. Dominick, S. M. and J. R. Tegart
"Low-g Propellant Transfer Using Capillary Devices"
AIAA, SAE and ASME Joint Propulsion Conference, 17th
Colorado Springs, CO
July 27-29, 1981, AIAA Paper 81-1507

14. Fester, D. A. and R. N. Eberhardt
"A Multimission Tank for Next Generation Spacecraft"
AIAA paper 81-1513
(Same conference as above)

15. Haise, F. W., Jr.
"Servicing Satellites from the Space Shuttle"
Grumman Aerospace Horizons, Volume 18, No.1, 1982

16. Goodman, J. R.
"Space Shuttle/Orbiter EVA and EVA Provisions"
In: Human Factors Society, Annual Meeting, 24th, Los Angeles CA
October 13-17, 1980, Proceedings (ABZ-2290109-54)
IAA #A82-22917

17. Vandenkerckhove, J. A.
"Satellite Refueling in Orbit"
In: Communications Satellite Systems Conference, 9th
San Diego, CA, March 7-11, 1982, Collection of Technical Papers
(AIAA 82-0514)

18. SSD 80-0175-1
"MMS In-Orbit Refueling Study Analysis & Design"
Rockwell

19. NASA CR-134748 CASD-NAS-74-068
"Fluid Management Systems Technology Summaries"
General Dynamics

20. SAMSO TR 74-168
"In-Space Servicing of a DSP Sat."
Volume III, 16439-6637-RU-00
TRW

C. STORAGE OF CRYOGENICS IN SPACE

1. Rpt. #NASA-CR-96833
   "The Meteoroid Hazard to the Hydrogen Storage Tank"
   Arthur O. Little, Inc., Cambridge, Mass.

2. Rpt. #NASA-TM-X-60666
   Proceedings of the Conference on Long-Term Cryo-propellant Storage in Space

3. Rpt. #AIAA Paper 82-0075
   "Thermodynamic Optimization of a Cryogenics Storage System for Minimum Boiloff--Space Applications"
   Martin Marietta Aerospace, Denver, CO

4. Rpt. #AIAA Paper 72-142
   "Thermal/Structural Optimization of Cryogenic Storage Systems"
   McDonnell Douglas Astronautics Co.

5. Rpt. #NASA-CR-165321
   "Conceptual Design and Analysis of Orbital Cryogenic Liquid Storage and Supply Systems"
   Martin Marietta

6. Rpt. #NASA-CR-112557
   "Active Refrigeration for Cryogenic Storage in Space"
   Bellcomm, Inc., Washington, D.C.

7. Rpt. #AIAA Paper 82-0075
   "Thermodynamic Optimization of a Cryogenic Storage System for Minimum Boiloff--Space Applications"
   Martin Marietta

8. 79A31012*
   A Cryogenic Helium II System for Spacelab
   NASA, Huntsville

9. Rpt. #AIAA Paper 77-763
   "Cryogenic Temperature Control by Means of Energy Storage Materials--for Long Space Voyages"
   Lockheed Missiles & Space Co.

10. 76 A3 1484
    "Cryogenic Recovery--of Space Shuttle Propellants"
    NASA Kennedy Space Center

11. 75A43991
    "Thermal Performance Characteristics of a Combined External Insulation System Under Simulated Space Vehicle Operating Conditions--Liquid Hydrogen Storage"
    McDonnell Douglas Astronautics Co.

12. Rpt. #AIAA Paper 74-1151
"Space Storable Propellant Acquisition System"
Martin Marietta Aerospace Co.

13. Rpt. #AIAA Paper 74-726
"Development of a Reusable Flightweight Cryogenic Storage System"
General Dynamics Corp.

14. CNT #: NAS9-10348
"Long-Term Cryogenic Space Storage System"

Beach Aircraft Corp.

15. Rpt. #NASA-CR-165495
"Cryogenic Fluid Management Experiment"
Martin Marietta

16. Rpt. #PB80-802051
"Cryogenic Refrigeration, Volume 3"
National Technical Information Service

17. Rpt. #NASA-TN-D-8320
"Thermal Performance of an Integrated Thermal Protective System for Long-Term Storage of Cryogenic Propellants in Space"
NASA, Lewis

18. Rpt. #NASA-CR-114493
"Space Storable Propellant Acquisition System"
Martin Marietta

19. NASA-CR-134482
"Study of Thermodynamic Vent and Screen Baffle Integration for Orbital Storage and Transfer of Liquid Hydrogen"
McDonnel Douglas Astronautics (NASA Lewis)

20. 72N19952*
"Long Term Cryogenic Storage System Integration"
NASA, Huntsville

21. Rpt. #NASA-CR-151718
"Orbital Propellant Handling and Storage for Large Space Programs, Volume 1"
General Dynamics

22. MCR-82-561
Contract F04611-82-C-0023
"Long Term Cryogenic Storage Technology Conference"
May 12-13, 1982 at Martin Marietta

23. NASA-CR-135143
"Spacelab Cryogenic Fluid Management Experiment"
McDonnell Douglas Astronautics

24. Rpt. #NASA-CR-134911
"Low-G Fluid Transfer Technology Study"
General Dynamics

APPENDIX B
EXTRACTION FROM THE USER REQUIREMENTS AND BENEFITS CATALOG

This appendix is an extraction from the User Requirements and Benefits Catalog as issued by TRW as part of the Space Station Needs, Attributes and Architectural Options Study (NASW-3681). Extracted are the five sets of standard forms covering the five TDMs emphasized by this study. Coding information for payload element type and crew skill level/type is contained in the last two pages.

PAYLOAD ELEMENT NAME: Buildup of Manipulator

CODE: TRWX2008

CONTACT
Name: Barbara Askins, PM01
Address: MSFC
Huntsville, AL

FTS: 872-5311
Telephone: (205) 453-0541

STATUS

_ Operational
_ Approved
_ Planned
_ Candidate
_ Opportunity

First flight, yr 1994
No. of flights 1
Duration of Flight, days 20

OBJECTIVE Verify and demonstrate on-orbit assembly procedures for large structural parts. This TDM directly benefits the evolutionary growth of the space station.

TYPE

_ Science and Applications (non-commercial)

_ Commercial

X Technology Development

_ Operations

Type Number (see Table A) 14, 15

Importance of the Space Station to this Element

1 = low value but could use

10 = vital

Scale 1 - 10 9

DESCRIPTION This TDM is designed to demonstate space station crew methods and procedures to manipulate and assemble relatively large items of equipment needed to grow (evolve) the space station or assemble other space vehicles. In order that the TDM is not dead-ended, the buildup of the space station remote manipulator assembly (RMA) is used for this demonstraton. This buildup via structural elements, cables, etc. to make mobile the initial fixed manipulator capability is assumed to occur as one of the first space station growth elements.

TDM-1

Initiation Date 18 March 1983

Update _____

ORBIT CHARACTERISTICS N/A

Apogee, km _____ Perigee, km _____ Tolerance + _____ - _____

Inclination, deg _____ Tolerance + _____ - _____

Nodal Angle, deg _____ Ephemeris accuracy, m _____

Escape dV Required, m/s _____

POINTING/ORIENTATION N/A

View direction _ Inertial _ Solar _ Earth

Truth Sites (if known) _____

Pointing accuracy, arc sec _____ Field of view, deg _____

Pointing Stability (Jitter) arc sec/sec _____

Special Restrictions (Avoidance) _____

POWER TBD

_ AC _ DC

	Power, W	Duration, hrs/day	
Operating	_____	_____	
Standby	_____	_____	_ Continuous
Peak	_____	_____	

Voltage, V _____ Frequency, Hz _____

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DATA/COMMUNICATIONS TBD

Monitoring requirements:

_ None _ Realtime _ Offline _ Other _____

_ Encryption/Decryption Required

_ Uplink Req.: Command Rate (kb/s) _____ Frequency (MHz) _____

_ On-Board Data Processing Required

Description:

_____

Date Types: _ Analog _ Digital _ Hrs/Day _____

Film (Amount) _____ Voice (Hrs/Day) _____

Live TV (Hrs/Day) _____ Other _____

On-Board Storage (MBIT) _____

Data Dump Frequency (Per Orbit) _____

Recording Rate (kb/s) _____ Downlink Frequency (MHz) _____

Initiation Date 18 March 1983 Update _____

THERMAL TBD

Active _ Passive

Temperature, deg C
operational min _____ max _____
non-operational min _____ max _____

Heat Rejection, w
operational min _____ max _____
non-operational min _____ max _____

EQUIPMENT PHYSICAL CHARACTERISTICS TBD

Location: _ Internal _ External _ Remote

Equipment ID/Function _ Pressurized _ Unpressurized

L,m _____ W,m _____ H,m _____ Stowed
L,m _____ W,m _____ H,m _____ Deployed

Launch mass, kg _____

Consumables Types _____

Acceleration sensitivity, g min _____ max _____

CREW REQUIREMENTS

Crew Size 3 (2 EVA, 1 IVA) Task Assignment Build up and test movable remote manipulator

Skills (See Table B)

SKILL	5	5	5			
LEVEL	3	3	3			
Hrs/Day	6	6	6			

EVA X Yes _ No Reason Buildup Manipulator Hrs/EVA 40

SERVICING/MAINTENANCE N/A

SERVICE: Interval, days _____ Consumables, kg _____
Returnables, kg _____ Man Hours _____

CONFIGURATION CHANGES: Interval, day _____ Man/Hrs Req. _____
Deliverables, kg _____ Returnables, kg _____

SPECIAL CONSIDERATIONS/See Instructions This TDM assumes that the space station architecture starts with a fixed manipulator capability and is expanded to have a capability for a manipulator that is movable on a track or similar system. This TDM avails itself of the expansion to this capability to demonstrate technologies associated with such buildups and growth of the space station. These technologies are used.

Initiation Date 18 March 1983 Update _____

MISSION BENEFITS

Social and Performance: Will demonstrate technologies needed as the space station grows and evolves by adding significant structures. The same technology is applicable to assembling large spacecraft on orbit.

Commercial, Financial Expectations:

Operational Economies and Capabilities: Will assure capability to perform on orbit the operations related to assembly and construction required to grow the space station from 1995-2000 and beyond.

SPACE STATION IMPLEMENTATION OPTIONS

Initiation Date 18 March 1983

Update _____

PAYLOAD ELEMENT NAME: On-Orbit Spacecraft Assembly/Test

CODE: TRWX2009

CONTACT
Name: Barbara Askins, PM01
Address: MSFC
Huntsville, AL

FTS: 872-5311
Telephone: (205) 453-0541

TYPE

_ Science and Applications (non-commercial)

_ Commercial

X Technology Development

_ Operations

Type Number (see Table A): 14, 15

STATUS

_ Operational
_ Approved
_ Planned
_ Candidate
_ Opportunity

First flight, yr: 1992
No. of flights: 1
Duration of Flight, days: 45

OBJECTIVE Demonstrate and verify feasibility of on-orbit assembly and test of spacecraft. The operation investigated by this TDM is uniquely related to a space station since the space station provides time for longer-duration, more-flexible operations than conveniently possible with the Shuttle.

Importance of the Space Station to this Element

1 = low value but could use

10 = vital

Scale 1 - 10: 9

DESCRIPTION Using a simulated spacecraft, major elements of an on-orbit spacecraft assembly and test operation are demonstrated. This demonstration would remove the core and the attachable elements of a spacecraft from the STS, store them on or near the space station, and then proceed in an orderly way to conduct assembly and test operations using combinations of EVA and IVA as appropriate. The space station would provide power, commanding, and data analysis to support the operation.

TDM-2

Initiation Date 18 March 1983

Update _____

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ORBIT CHARACTERISTICS N/A

Apogee, km _____ Perigee, km _____ Tolerance + _____ - _____

Inclination, deg _____ Tolerance + _____ - _____

Nodal Angle, deg _____ Ephemeris accuracy, m _____

Escape dV Required, m/s _____

POINTING/ORIENTATION N/A

View direction _ Inertial _ Solar _ Earth

Truth Sites (if known) _____

Pointing accuracy, arc sec _____ Field of view, deg _____

Pointing Stability (Jitter) arc sec/sec _____

Special Restrictions (Avoidance) _____

POWER

_ AC X DC

	Power, W	Duration, hrs/day	
Operating	>2000		
Standby	>500		_ Continuous
Peak	TBD		

Voltage, V 28 or 120 Frequency, Hz _____

DATA/COMMUNICATIONS

Monitoring requirements:

_ None X Realtime X Offline _ Other _____

_ Encryption/Decryption Required

X Uplink Req.: Command Rate (kb/s) 2 Frequency (MHz) TBD

X On-Board Data Processing Required

Description:

_____

Date Types: _ Analog X Digital Hrs/Day 8

Film (Amount) TBD Voice (Hrs/Day) _____

Live TV (Hrs/Day) TBD Other _____

On-Board Storage (MBIT) TBD

Data Dump Frequency (Per Orbit) Once

Recording Rate (kb/s) TBD Downlink Frequency (MHz) TBD

Initiation Date 18 March 1983 Update _____

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THERMAL TBD
_ Active _ Passive

Temperature, deg C	operational min		max	
	non-operational min		max	
Heat Rejection, w	operational min		max	
	non-operational min		max	

EQUIPMENT PHYSICAL CHARACTERISTICS
Location: _ Internal _ External _ Remote
Equipment ID/Function _ Pressurized _ Unpressurized

L,m	4.2	W,m	10.0	H,m	4.2	Stowed
L,m	7.5	W,m	7.5	H,m	7.5	Deployed

Launch mass, kg Approx. 2500
Consumables Types Hydrazine
Acceleration sensitivity, g min N/A max

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CREW REQUIREMENTS
Crew Size 2 (EVA), 1 (IVA) Task Assignment Build up/Check out Spacecraft

Skills (See Table B)

SKILL	5	5	7			
LEVEL	3	3	3			
Hrs/Day	8	8	8			

EVA X Yes _ No Reason Install Equipment Hrs/EVA 96

SERVICING/MAINTENANCE TBD
SERVICE: Interval, days Consumables, kg
Returnables, kg Man Hours
CONFIGURATION CHANGES: Interval, day Man/Hrs Req.
Deliverables, kg Returnables, kg

SPECIAL CONSIDERATIONS/See Instructions After spaceraft assembly and test operations are complete, the simulated spacecraft is either de-orbited or carried back in a Shuttle. Components may be left as spares, particularly if standard modules are a part of the configuration. Uses standard berthing port, EVA, IVA, and manipulator capabilities on space station. May use assembly platform if available.

Initiation Date 18 March 1983 Update

MISSION BENEFITS

Social and Performance:

Commercial, Financial Expectations:

Operational Economies and Capabilities: This TDM is expected to confirm the hypothesis that performance of some spacecraft assembly and test operations on orbit using a space station is cost effective compared to doing similar operations on the ground. If confirmed by this TDM, savings will accrue to subsequent spacecraft designs.

SPACE STATION IMPLEMENTATION OPTIONS

Initiation Date 18 March 1983

Update _____

PAYLOAD ELEMENT NAME	CODE
Large Antenna Construction	TRWX2005

CONTACT
Name Barbara Askins, PM01
Address MSFC
Huntsville, AL

FTS: 872-5311
Telephone (205) 453-0541

STATUS TBD

_ Operational
_ Approved
_ Planned
_ Candidate
_ Opportunity

First flight, yr 1994
No. of flights 1
Duration of Flight, days 60

OBJECTIVE Demonstrate on-orbit capability to construct, adjust, and measure characteristics of a large antenna. This is a long-term, iterative process, ideally suited to be done on a space station (compared to Shuttle) where longer times are interrupted sequences are possible.

TYPE

_ Science and Applications (non-commercial)

_ Commercial

X Technology Development

_ Operations

Type Number (see Table A) 10, 14, 15

Importance of the Space Station to this Element

1 = low value but could use

10 = vital

Scale 1 - 10 8

DESCRIPTION
A large antenna is carried to orbit disassembled. ASE for alignment and RF pattern measurements is also carried to orbit. The antenna is assembled and adjustments made to the parabolic shape and feed location. Upon completion of assembly and adjustment, pattern measurements are made using a teleoperator maneuvering system (TMS) carrying signal generation and field strength measurement equipment.

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TDM-3

Initiation Date 18 March 1983

Update _____

R5-262-82

ORBIT CHARACTERISTICS N/A

Apogee, km _____ Perigee, km _____ Tolerance + _____ - _____

Inclination, deg _____ Tolerance + _____ - _____

Nodal Angle, deg _____ Ephemeris accuracy, m _____

Escape dV Required, m/s _____

POINTING/ORIENTATION N/A

View direction _ Inertial _ Solar _ Earth

Truth Sites (if known) _____

Pointing accuracy, arc sec _____ Field of view, deg _____

Pointing Stability (Jitter) arc sec/sec _____

Special Restrictions (Avoidance) _____

POWER TBD

_ AC _ DC

	Power, W	Duration, hrs/day	
Operating	_____	_____	_ Continuous
Standby	_____	_____	
Peak	_____	_____	

Voltage, V _____ Frequency, Hz _____

DATA/COMMUNICATIONS TBD

Monitoring requirements:

_ None _ Realtime _ Offline _ Other _____

_ Encryption/Decryption Required

_ Uplink Req.: Command Rate (kb/s) _____ Frequency (MHz) _____

_ On-Board Data Processing Required

Description:

_____

Date Types: _ Analog _ Digital _ Hrs/Day _____

Film (Amount) _____ Voice (Hrs/Day) _____

Live TV (Hrs/Day) _____ Other _____

On-Board Storage (MBIT) _____

Data Dump Frequency (Per Orbit) _____

Recording Rate (kb/s) _____ Downlink Frequency (MHz) _____

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Initiation Date 18 March 1983 Update _____

THERMAL TBD
_ Active _ Passive

Temperature, deg C	operational	min		max
	non-operational	min		max
Heat Rejection, w	operational	min		max
	non-operational	min		max

EQUIPMENT PHYSICAL CHARACTERISTICS
Location: _ Internal X External _ Remote
Equipment ID/Function _ Pressurized X Unpressurized

L,m 25	W,m 4.5 (dia)	H,m		Stowed
L,m 60 (dia)	W,m 20	H,m		Deployed

Launch mass, kg TBD
Consumables Types N/A
Acceleration sensitivity, g min TBD max TBD

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CREW REQUIREMENTS
Crew Size 2 (EVA), 2 (IVA) Task Assignment Assemble/test antenna

Skills (See Table B)

SKILL	5	5	5	7		
LEVEL	3	3	2	3		
Hrs/Day	8	8	8	4		

EVA X Yes _ No Reason Assemble antenna Hrs/EVA 172

SERVICING/MAINTENANCE N/A
SERVICE: Interval, days _____ Consumables, kg _____
Returnables, kg _____ Man Hours _____
CONFIGURATION CHANGES: Interval, day _____ Man/Hrs Req. _____
Deliverables, kg _____ Returnables, kg _____

SPECIAL CONSIDERATIONS/See Instructions May require special adapter to interface with standard sapce station berthing ports. Use of EVA aids - manipulator, MMU, etc., required. Requires availability of TMS.

Initiation Date 18 March 1983 Update _____

MISSION BENEFITS

Social and Performance: Will demonstrate assembling, shaping, and aligning a very large antenna structure carried to space essentially disassembled. Will also measure RF characteristics of such an antenna. Successful completion of the TDM will make the technology available for such large antenna construction in space with the corollary improvement in performance.

Commercial, Financial Expectations:

Operational Economies and Capabilities:

SPACE STATION IMPLEMENTATION OPTIONS

Initiation Date 18 March 1983

Update _____

PAYLOAD ELEMENT NAME: Service/Refurbish Satellite (GRO)

CODE: TRWX2007

TYPE

_ Science and Applications (non-commercial)

_ Commercial

X Technology Development

_ Operations

Type Number 13, 14, 15 (see Table A)

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CONTACT
Name Barbara Askins, PM01
Address MSFC
Huntsville, AL

FTS: 872-5311
Telephone (205) 453-0541

STATUS TBD

_ Operational
_ Approved
_ Planned
_ Candidate
_ Opportunity

First flight, yr 1991
No. of Flights 1
Duration of Flight, days 20

Importance of the Space Station to this Element

1 = low value but could use

10 = vital

Scale 1 - 10 _____

OBJECTIVE Demonstrate various servicing technologies utilizing Gamma Ray Observatory (GRO), whose planned mission is complete circa 1991. GRO, berthed to the space station, is an ideal test bed for satellite servicing technology demonstrations for an extended period of time.

DESCRIPTION GRO, upon completion of its planned mission 2 years after a 1988 launch, remains at its operating altitude in a safed mode until space station is available. GRO altitude is then decreased and rendezvous with the space station accomplished (TMS may be required). Various servicing experiments and procedures are demonstrated such as component replacement, refurbishment, propellant transfer, etc. When these demonstrations are complete, GRO's useful life may have been extended allowing it to remain on orbit or, alternatively, it may be disposed of then as originally planned.

TDM-4

Initiation Date 18 March 1983

Update _____

ORBIT CHARACTERISTICS TBD

Apogee, km _____ Perigee, km _____ Tolerance + _____ - _____

Inclination, deg _____ Tolerance + _____ - _____

Nodal Angle, deg _____ Ephemeris accuracy, m _____

Escape dV Required, m/s _____

POINTING/ORIENTATION TBD

View direction _ Inertial _ Solar _ Earth

Truth Sites (if known) _____

Pointing accuracy, arc sec _____ Field of view, deg _____

Pointing Stability (Jitter) arc sec/sec _____

Special Restrictions (Avoidance) _____

POWER TBD

_ AC _ DC

	Power, W	Duration, hrs/day	
Operating			
Standby			_ Continuous
Peak			

Voltage, V _____ Frequency, Hz _____

DATA/COMMUNICATIONS

Monitoring requirements:

_ None X Realtime X Offline _ Other _____

_ Encryption/Decryption Required

X Uplink Req.: Command Rate (kb/s) _____ Frequency (MHz) _____

X On-Board Data Processing Required

Description:

_____

Date Types: _ Analog X Digital 8 Hrs/Day _____

Film (Amount) TBD Voice (Hrs/Day) _____

Live TV (Hrs/Day) TBD Other _____

On-Board Storage (MBIT) TBD

Data Dump Frequency (Per Orbit) _____

Recording Rate (kb/s) TBD Downlink Frequency (MHz) _____

Initiation Date 18 March 1983 Update _____

THERMAL

_ Active X Passive

Temperature, deg C
operational min _____ max _____
non-operational min _____ max _____

Heat Rejection, w
operational min _____ max _____
non-operational min _____ max _____

EQUIPMENT PHYSICAL CHARACTERISTICS

Location: _ Internal _ External _ Remote

Equipment ID/Function _ Pressurized _ Unpressurized

L,m _____ W,m _____ H,m _____ Stowed
L,m _____ W,m _____ H,m _____ Deployed
Launch mass, kg _____
Consumables Types _____
Acceleration sensitivity, g min _____ max _____

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CREW REQUIREMENTS

Crew Size 2 (EVA), 1 (IVA) Task Assignment Various Servicing Operations

Skills (See Table B)

SKILL	5	5	5			
LEVEL	3	3	3			
Hrs/Day	6	6	10			

EVA X Yes _ No Reason Perform Servicing Operations Hrs/EVA 80

SERVICING/MAINTENANCE N/A

SERVICE: Interval, days _____ Consumables, kg _____
Returnables, kg _____ Man Hours _____

CONFIGURATION CHANGES: Interval, day _____ Man/Hrs Req. _____
Deliverables, kg _____ Returnables, kg _____

SPECIAL CONSIDERATIONS/See Instructions Will use GRO exactly as designed. Servicing experiments and demonstrations will be designed around the "as is" GRO configuration. Will use standard manipulator and grapple capability on the space station. May need adapter to interface with standard berthing port.

Initiation Date 18 March 1983 Update _____

MISSION BENEFITS

Social and Performance:

Commercial, Financial Expectations:

Operational Economies and Capabilities: GRO, its mission completed, is a resource, on orbit, which is essentially free to this TDM.

SPACE STATION IMPLEMENTATION OPTIONS

Initiation Date 18 March 1983

Update _____

PAYLOAD ELEMENT NAME: Service Materials Processing Platform
CODE: TRWX2006

CONTACT
Name: Barbara Askins, PM01
Address: MSFC
Huntsville, AL

FTS: 872-5311
Telephone: (205) 453-0541

STATUS TBD

_ Operational
_ Approved
_ Planned
_ Candidate
_ Opportunity

First flight, yr 1991
No. of flights 1
Duration of Flight, days 5

OBJECTIVE Using the early space station, a TMS and a space platform, demonstrate technologies involved in servicing, resupplying, and harvesting a materials processing in space platform remote from the space station.

TYPE

_ Science and Applications (non-commercial)

_ Commercial

X Technology Development

_ Operations

Type Number 14, 15
(see Table A)

Importance of the Space Station to this Element

1 = low value but could use

10 = vital

Scale 1 - 10 7

DESCRIPTION A free-flying materials processing platform (MPS) is brought within TMS range of the space station. The TMS rendezvous with the platform, monitors its status, inspects it, harvests its completed product, and resupplies raw material. The TMS may reboost the platform.

TDM-5

Initiation Date 18 March 1983

Update _____

ORBIT CHARACTERISTICS
Apogee, km TBD Perigee, km TBD Tolerance + _____ - _____
Inclination, deg 28.5 Tolerance + _____ - _____
Nodal Angle, deg TBD Ephemeris accuracy, m _____
Escape dV Required, m/s N/A

POINTING/ORIENTATION TBD
View direction _ Inertial _ Solar _ Earth
Truth Sites (if known) _____
Pointing accuracy, arc sec _____ Field of view, deg _____
Pointing Stability (Jitter) arc sec/sec _____
Special Restrictions (Avoidance) _____

POWER N/A
_ AC _ DC

	Power, W	Duration, hrs/day	
Operating	_____	_____	
Standby	_____	_____	_ Continuous
Peak	_____	_____	

Voltage, V _____ Frequency, Hz _____

DATA/COMMUNICATIONS TBD
Monitoring requirements:

_ None _ Realtime _ Offline _ Other _____
_ Encryption/Decryption Required
_ Uplink Req.: Command Rate (kb/s) _____ Frequency (MHz) _____
_ On-Board Data Processing Required
_ Description:

_____

Date Types: _ Analog _ Digital Hrs/Day _____
Film (Amount) _____ Voice (Hrs/Day) _____
Live TV (Hrs/Day) _____ Other _____
On-Board Storage (MBIT) _____
Data Dump Frequency (Per Orbit) _____
Recording Rate (kb/s) _____ Downlink Frequency (MHz) _____

Initiation Date 18 March 1983 Update _____

THERMAL TBD

_ Active _ Passive

Temperature, deg C
operational min _____ max _____
non-operational min _____ max _____

Heat Rejection, w
operational min _____ max _____
non-operational min _____ max _____

EQUIPMENT PHYSICAL CHARACTERISTICS TBD

Location: _ Internal _ External _ Remote

Equipment ID/Function _ Pressurized _ Unpressurized

L,m _____ W,m _____ H,m _____ Stowed
L,m _____ W,m _____ H,m _____ Deployed

Launch mass, kg _____

Consumables Types _____

Acceleration sensitivity, g min _____ max _____

CREW REQUIREMENTS

Crew Size 2 (IVA) Task Assignment Service Free-Flyer

Skills (See Table B)

SKILL	5	7				
LEVEL	3	3				
Hrs/Day	8	8				

EVA _ Yes X No Reason _____ Hrs/EVA _____

SERVICING/MAINTENANCE

SERVICE: Interval, days _____ Consumables, kg _____
Returnables, kg _____ Man Hours _____

CONFIGURATION CHANGES: Interval, day _____ Man/Hrs Req. _____
Deliverables, kg _____ Returnables, kg _____

SPECIAL CONSIDERATIONS/See Instructions Teleoperator maneuvering system (TMS) is required. In addition to the relatively short mission time, there is the work related to the preparation and post-mission servicing of the TMS. Assumes a platform in near orbit exists.

Initiation Date 18 March 1983 Update _____

MISSION BENEFITS

Social and Performance:

Commercial, Financial Expectations: This TDM will help provide the data base upon which commercial processing of pharmaceuticals and other materials can be built.

Operational Economies and Capabilities: The successful completion of this TDM will demonstrate all aspects of rendezvousing and servicing of a free-flyer from the space station. Therefore, subsequent rendezvousing/servicing operations can be conducted with more confidence and lower risk.

SPACE STATION IMPLEMENTATION OPTIONS

Initiation Date 18 March 1983

Update _____

Payload Element Type
Page 1

Table A

SCIENCE AND APPLICATIONS

1. Astrophysics
2. Earth and Planetary Exploration
3. Environmental
4. Life Sciences
5. Materials Processing

COMMERCIAL

6. Earth and Ocean Observations
7. Communications
8. Materials Processing
9. Industrial Services

TECHNOLOGY DEVELOPMENT

10. Materials and Structures
11. Energy Conversion
12. Computer Science and Electronics
13. Propulsion
14. Controls and Human Factors
15. Space Station Systems and Operations
16. Fluid and Thermal Physics, Physics and Chemistry

OPERATIONS

17. Maintenance

18. Other

Initiation Date 10 December 1982

Update _____

Table B

Skill Type

1. No Special Skill Required
2. Medical/Biological
3. Physical Sciences
4. Earth and Ocean Sciences
5. Engineering
6. Astronomy
7. Spacecraft Systems

Skill Levels

1. Task Trainable
2. Technician
3. Professional

APPENDIX C
SPECIFIC REQUIREMENTS IMPOSED ON THE SPACE STATION

This appendix provides information concerning six specific requirements the five TDMs being defined by this study impose on the space station. The six items were identified by the Technology Development Mission Working Group.

KEY TDM/SS INTERFACE DATA

ITEM	TECHNOLOGY DEVELOPMENT MISSION 1	2	3	4	5
1. POWER	NONE	2.5 kW	2.0 kW	2.5 kW	1 kW
2. CREW TIME	80 HRS.	200 HRS.	340 HRS.	80 HRS.	100 HRS.
3. NO. OF SERVICINGS	NONE	ONE	ONE	ONE	FIVE
4. NO. OF TIMES SS USED AS TRANS-PORTATION NODE	ONE	ONE	ONE	TWO	FIVE
5. INTERNAL VOLUME	$0.2M^3$ ($8\ FT^3$)	$0.5\ M^3$ ($20\ FT^3$)	$0.5M^3$ ($20\ FT^3$)	$0.1M^3$ ($4\ FT^3$)	$0.4M^3$ ($16\ FT^3$)
6. NO. OF ATTACHMENT POINTS TO SS	FOUR	ONE	TWO	TWO	TWO

1. POWER	POWER DRAWN FROM SPACE STATION AT ATTACHMENT PORT. MAY BE GIVEN IN PEAK, AVERAGE AND STANDBY VALUES. VOLTAGE GIVEN, IF KNOWN. TIME PROFILE GIVEN, IF KNOWN.
2. CREW TIME	EVA & IVA BOTH WITH AMOUNT ALLOCATED TO EACH. ACTUAL WORK TIME ONLY.
3. NO. OF SERVICINGS	NUMBER OF TIMES THE SPACE STATION IS ACTUALLY VISITED FOR A SERVICE EVENT (AS DISTINGUISHED FROM TRANSPORTATION NODE).
4. NO. OF TIMES SS IS USED AS TRANSPORTATION NODE	NUMBER OF TIMES SPACE STATION IS USED AS A STOPPING OR TRANSFER POINT. A TMS USE COUNTS AS A TRANSPORTATION NODE.
5. INTERNAL VOLUME	VOLUME WITHIN PRESSURIZED SPACE.
6. NO. OF ATTACHMENT POINTS TO SS	STANDARD ATTACHMENT PORTS OR SPECIAL ATTACHMENT STRUCTURES. MANIPULATOR ARMS, ETC. NOT COUNTED.

KEY TDM/SS INTERFACE DATA

TDM 1 BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY

ITEM	REQUIREMENT	COMMENT
1. POWER	NONE	POWER IS NOT PART OF TDM REQ. RATHER, IT IS PART OF SS ALLOCATION (EST. 2-3 KW).
2. CREW TIME	80 HRS.	APPROX 50/50 EVA/IVA. MAY BE CONSIDERED AS PART OF TIME ALLOCATED TO SS ITSELF.
3. NO. OF SERVICINGS	NONE	NOT INVOLVED IN A VISIT TO THE SS. TDM WORK IS DONE ON SS ITSELF.
4. NO. OF TIMES SS IS USED AS TRANSPORTATION NODE	ONE	SS IS FINAL DESTINATION OF EQUIPMENT.
5. INTERNAL VOLUME	$0.2M^3$ ($8\ FT^3$)	BECOMES PERMANENT PART OF SS.
6. NO. OF ATTACHMENT POINTS TO SS	FOUR	UNIQUE STRUCTURAL ATTACHMENTS WHICH ARE PART OF SS DESIGN. (NOT A STANDARD PORT)

KEY TDM/SS INTERFACE DATA

TDM 2 ON-ORBIT SPACECRAFT ASSEMBLY, TEST & LAUNCH

ITEM	REQUIREMENT	COMMENT
1. POWER	2.5 kW AVERAGE 3.0 kW PEAK 0.5 kW STANDBY	MAY BE LOWER UNTIL ASSEMBLY IS NEARLY COMPLETE. PROBABLY 28 VDC.
2. CREW TIME	200 HRS.	APPROX. 50/50 IVA & EVA. ON-ORBIT TRAINING AND REHEARSAL NOT INCLUDED.
3. NO. OF SERVICINGS	ONE	TDM SPACECRAFT HAS ONLY ONE SERVICE EVENT AT THE SS.
4. NO. OF TIMES SS IS USED AS TRANSPORTATION NODE	ONE	TDM SPACECRAFT LAUNCHED FROM SS ONLY ONCE.
5. INTERNAL VOLUME	$0.5M^3$ ($20\ FT^3$)	SPECIAL CHECKOUT EQUIPMENT INSTALLED FOR CONTINUED USE.
6. NO. OF ATTACHMENT POINTS TO SS	ONE	POWER, FLUID, SIGNAL REQUIRED AT INTERFACE AS WELL AS PHYSICAL INTERFACE FOR BERTHING.

KEY TDM/SS INTERFACE DATA

TDM 3 LARGE ANTENNA STRUCTURE DEPLOYMENT

ITEM	REQUIREMENT	COMMENT
1. POWER	2.0 kW AVERAGE 3.0 kW PEAK 0.5 kW STANDBY	PROBABLY 28 VDC. MAY BE HIGHER VOLTAGE DC (120-200V)
2. CREW TIME	340 HRS.	APPROX. 50/50 IVA & EVA. ON-ORBIT TRAINING AND REHEARSAL NOT INCLUDED.
3. NO. OF SERVICINGS	ONE	TDM HAS ONLY ONE SERVICE EVENT AT SS.
4. NO. OF TIMES SS IS USED AS TRANSPORTATION NODE	ONE	TDM ANTENNA MAY BE MADE PART OF A SATELLITE ASSEMBLY & RELEASED TO ORBIT.
5. INTERNAL VOLUME	$0.5M^3$ (20 FT^3)	SPECIAL CHECKOUT, SUPPORT EQUIPMENT FOR CHECKOUT, ALIGNMENT, ANALYSIS.
6. NO. OF ATTACHMENT POINTS TO SS	TWO	PHYSICAL ATTACHMENT POWER SIGNAL INTERFACE REQUIRED FOR ANTENNA SYSTEM PLUS TMS PORT.

KEY TDM/SS INTERFACE DATA

TDM 4 SERVICE/REFURBISH SATELLITE (GRO)

ITEM	REQUIREMENT	COMMENT
1. POWER	2.5 kW	
2. CREW TIME	80 HRS.	APPROX. 50/50 IVA/EVA. ON-ORBIT TRAINING/REHEARSAL NOT INCLUDED.
3. NO. OF SERVICINGS	ONE	TDM HAS ONLY ONE SERVICE EVENT AT SS.
4. NO. OF TIMES SS IS USED AS TRANSPORTATION NODE	TWO	FOR TDM, GRO (AS EXAMPLE SATELLITE) IS RETRIEVED ONCE FROM ORBIT AND AFTER SERVICING, RELEASED AGAIN TO ORBIT.
5. INTERNAL VOLUME	$0.1M^3$ ($4 FT^3$)	PROBABLY NEGLIGIBLE.
6. NO. OF ATTACHMENT POINTS TO SS	TWO	BERTHING PORT WITH PHYSICAL ATTACHMENT, POWER, PROPELLANT & SIGNAL FOR SATELLITE PLUS TMS PORT.

KEY TDM/SS INTERFACE DATA

TDM 5 SERVICING FREE-FLYING MATERIALS PROCESSING PLATFORM

ITEM	REQUIREMENT	COMMENT
1. POWER	1 kW	FOR USE DURING EARLY TESTING BEFORE TEST ON FREE FLYER. 28 VDC
2. CREW TIME	100 HRS.	ALL IVA. BASIC OPERATION REQ. APPROX. 10 HRS. 100 HRS. COVERS REPEAT TESTS & DEVEL. TEST REQ. OF TDM.
3. NO. OF SERVICINGS	5	TDM WILL SCHEDULE SEVERAL SERVICE VISITS FROM SS TO FREE FLYER.
4. NO. OF TIMES SS IS USED AS TRANSPORTATION NODE	5	TDM USES TMS TO SERVICE FREE FLYER.
5. INTERNAL VOLUME	0.4 M^3(16 FT^3)	FOR SIMULATED RAW MATERIAL/ FINISHED PRODUCT STORAGE. MAY BE EXTERNAL VOLUME.
6. NO. OF ATTACHMENT POINTS TO SS	TWO	TMS DOCKING PORT AND ATTACH-MENTS FOR RAW MATERIAL FINISHED PRODUCTS WHEN EXTERNAL TO SS.

APPENDIX D

ACRONYMS

ACM	Attitude Control Module
ACS	Attitude Control System
AM	Antenna Module
ASE	Aerospace Support Equipment
C&DH	Communications and Data Handling
CDHM	Communications and Data Handling Module
CER	Cost Estimating Relationships
EPM	Electrical Power Module
EVA	Extra Vehicular Activity
FF	Free Flyer
GEO	Geosynchronous Orbit
GRO	Gamma Ray Observatory
HUD	Heads-Up Display
IRAD	Internal Research and Development
IVA	Intra Vehicular Activity
LDEF	Long Duration Exposure Facility
LEO	Low Earth Orbit
MMS	Multi Mission Spacecraft
MMU	Manned Maneuvering Unit
MPP	Materials Processing Platform
MS	Manipulator System
MSS	Manned Space Station
O.D.	Orbital Determination
ORU	Orbital Replacement Units
OTV	Orbital Transfer Vehicle
P/L	Payload
PP	Processing Platform
RMA	Remote Manipulator Arm
RMS	Remote Manipulator System
SADE	Structural Assembly Demonstration Experiment
S/C	Spacecraft
SS	Space Station
STS	Space Transportation System
SSUM	Satellite Servicing Users Model
TD	Technology Development
TDA	Technology Development Area
TDM	Technology Development Mission
TDE	Technology Development Element
T.P.	Telemetry Processing